UNIVERSITY OF ALBERTA

A PETROLOGIC COMPARISON OF THE FRENCHMAN AND UPPER EDMONTON FORMATIONS

A THESIS

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by

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Petrologic Comparison of the Frenchman and Upper Edmonton Formations", submitted by Byung IL Chi, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Sandstones from eight sections of the Frenchman Formation in the Cypress Hills Plateau and southern Saskatchewan, and from four sections of the Upper Member of the Edmonton Formation along the Red Deer Valley in central Alberta were studied by size analysis, thin section petrography and heavy mineral identification in order to compare these approximately time equivalent units.

Frenchman sandstones are characterized by dusty yellow to yellowish gray colour, moderate sorting, higher content of plagioclase than potassic feldspars, and a dominance of hornblende, epidote and garnet as heavy accessory minerals ; the Upper Member of the Edmonton Formation is grayish white to yellowish gray, has poor sorting, a higher percentage of potassic feldspars than plagioclase, and a preponderance garnet, apatite and zircon amongst the heavy minerals.

Size parameters suggest that the two formations were deposited under similar fluviatile conditions.

The compositions indicate that both formations had sources which were primarily sedimentary with lesser amounts of metamorphic, plutonic and volcanic rocks, but that these source areas differed in the kind of igneous material contributed. The Upper Edmonton sandstones were derived from terrains to the west of this formation. Source areas of the Frenchman sandstones are not known but may have included shield rocks to the northeast.

The stratigraphic variation of hornblende frequencies in the Frenchman Formation may be used in correlating stratigraphic units within the formation, and the absence of hornblende and increase in tourmaline in the Ravenscrag Formation are useful criteria for differentiating this formation from the Frenchman at approximately the Tertiary-Cretaceous boundary.

ACKNOWLEDGEMENTS

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CHAPTER ONE

INTRODUCTION

General Statement

The Frenchman Formation of southeastern Alberta and southwestern Saskatchewan was being deposited at the same time as the Upper Member of the Edmonton Formation of central Alberta according to existing paleontologic evidence. The aim of this study was to carry out a petrologic comparison of the sandstones of these two lithologic units in order to make an evaluation of the provenance and depositional patterns of sediments in the Western Canada Basin during latest Upper Cretaceous time. The locations of eight sections of the Frenchman Formation and four of the Upper Member of the Edmonton Formation which were sampled for study are shown in figure 1.

Previous Work

Frenchman Formation

Dawson (1875) and McConnell (1885) made the first geological reconnaissance studies in southern Alberta and Saskatchewan. More detailed investigations in southern Alberta have been made by Davis (1918), Dyer (1927), Williams and Dyer (1930) and Russell and Landes (1940). The stratigraphy, structure, petrography and paleontology in southern Saskatchewan have been studied by McLearn (1927), Fraser *et al*. (1935), Russell (1932, 1948, 1950), Furnival (1946) and Kupsch (1956, 1957). The name Frenchman Formation was introduced by Furnival (1946).

Edmonton Formation

The coal bearing strata observed around the city of Edmonton and the strata exposed along the Red Deer River had been examined by Selwyn (1874), who named them

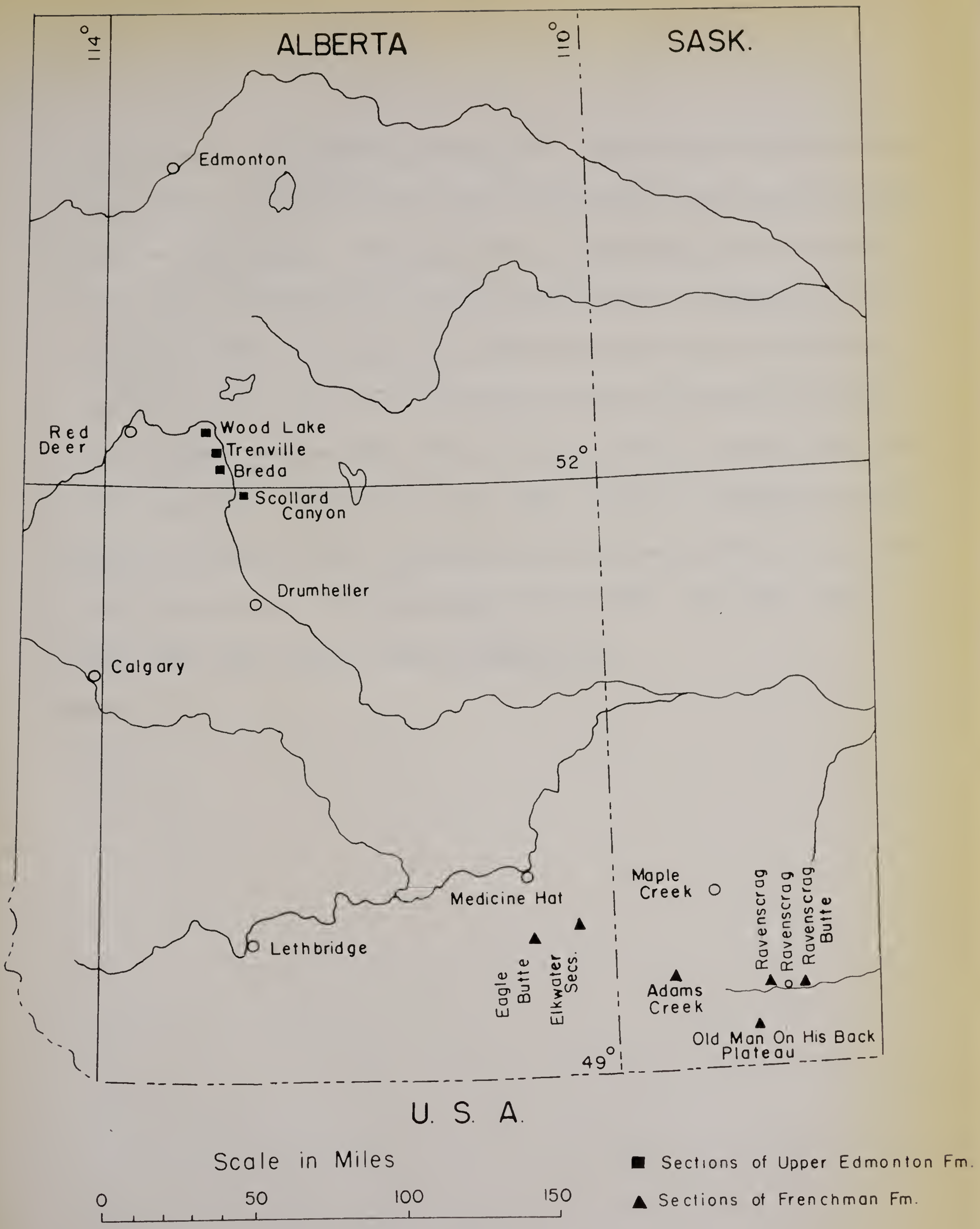


Figure 1. Location Map

"Edmonton beds" , Tyrrell (1886) and Dowling (1910) . Brown (1914) studied the flora and fauna in order to correlate the typical Lance Creek Formation of Wyoming with equivalent formations in New Mexico , Montana and Alberta. Detailed study of the stratigraphy , paleontology , and depositional environment of this formation was carried out by Allan and Sanderson (1945) . Sternberg (1947) studied the dinosaurian fauna and Bell (1945) subdivided the flora. The Kneehills Tuff has been studied and described by Sanderson (1931) , Williams and Dyer (1930) , Allan and Sanderson (1945) , Sternberg (1947) , Bell (1949) , Ower (1960) , Elliott (1960) , Ritchie (1960) , Folinsbee , Baadsgaard and Lipson (1961) and Shafiqullah (1963) . The Cretaceous-Tertiary boundary problem in central and western Alberta areas has been examined by Rutherford (1947) , Ower (1958 , 1960) , Elliott (1958, 1960), Campbell (1962) and Lerbekmo (1964).

CHAPTER TWO

STRATIGRAPHY

Frenchman Formation

The former Ravenscrag Formation, as defined by Davis (1918), embraced Laramie of McConnell (1885) and Lance of Rose (1916) and was divided into an upper and a lower unit based on lithologic and faunal differences (McLearn, 1927; Fraser *et al*. 1935). Furnival (1946) assigned the name Frenchman Formation to the strata previously described as the lower Ravenscrag Formation. The Frenchman Formation lies between the Battle Formation and the Ravenscrag Formation, formerly known as the upper Ravenscrag Formation. The upper contact of the formation has been defined only in Saskatchewan where it was placed at the base of the prominent coal seam referred to as No. 1 or Ferris seam in the Eastend and Ravenscrag Butte area (Furnival, 1946). This coal seam has not been observed in Alberta. The lower contract is a disconformity. The generalized stratigraphic relationships are summarized in Table 1. The formation rests on the Battle, Whitemud, or Eastend Formations depending upon the magnitude of erosion prior to its deposition. The relations of the Frenchman to underlying formations and to the overlying Ravenscrag Formation in the area studied are shown in figure 2.

In most areas the Frenchman Formation is composed of two lithologic facies (zones of Fraser, *et al*. 1935; phases of Russell, 1948; facies of Kupsch, 1956).

One facies is composed chiefly of sandstone which is massive, fine to coarse grained, crossbedded, and mostly friable, but with local large concretions cemented by calcium carbonate. The sand is yellowish gray or dusky yellow, and weathers light brown. The medium to fine sands are interbedded with silt and clay. Plant fragments, lignitic fossil wood, thin lignite beds, and iron concretions are

	Cypress Hills and Wood Mountain	Southern Saskatchewan		Cypress Hills	Eastern Montana U. S. A.	Red Deer River Valley			
	after McConnell (1885)	after McLearn (in Fraser et al) (1935)		after Furnival (1946)	after Bell (1949)	after Allan and Sanderson (1945)		after Ower (1960)	
PALEOCENE	Laramie	Ravenscrag	Upper	Ravenscrag	Fort Union	Paskapoo		Paskapoo	
UPPER CRETACEOUS			Lower	Frenchman	Hell Creek	Edmonton	Upper Member	Edmonton	Member E (Coaly)
		Whitemud	No. 4 zone	Battle	Fox Hills		-- Kneehills Tuff -- Mauve sh. White ss. Middle Member		---Kneehills Tuff--- Mauve sh. White ss. Member D
			No. 3 zone	Whitemud	Fox Hills (Colgate member)				
			No. 2 zone						
			No. 1 zone						
	Fox Hills	Eastend		Eastend	Fox Hills				Member C (Coaly)
							D.M.T. Lower Member		D.M.T. Member B (Non Coaly)
									Member A (Coaly)
	Pierre	Bearpaw		Bearpaw	Bearpaw	Bearpaw		Bearpaw	

Table 1. Stratigraphic nomenclature and relationships of the latest Upper Cretaceous rocks.

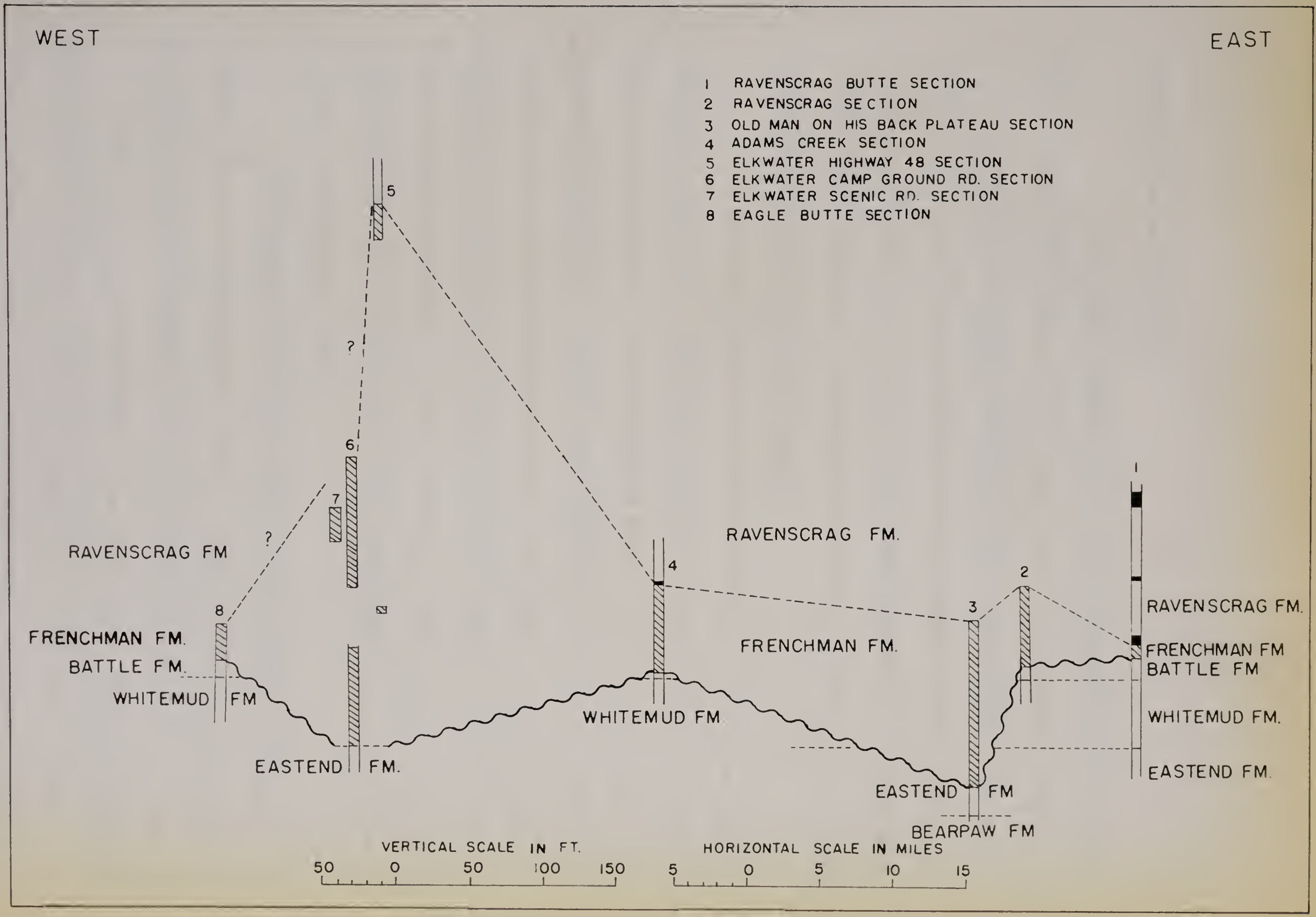


Figure 2. Diagram showing relations of the Frenchman Formation to underlying formations and to the overlying Ravenscrag Formation. (Modified after Furnival, 1946).

observed in the sand facies.

The second facies is greenish-gray to brownish-gray bentonitic clay and shales. Interbedded in places with the clay are very fine grained sands which are very similar to some Eastend Formation sands (Kupsch, 1956). Bone fragments representing dinosaurs, turtles, and fishes were observed by Russell (1948). He also indicated that no bones were found in the sand facies. Kupsch (1956) observed in the Knollys-Dollard area that these two facies may occur either at the bottom or at the top of the formation and that they may replace each other laterally.

The Frenchman Formation has a wide distribution in southeastern Alberta and southern Saskatchewan. Outcrops in southeastern Alberta are found along the three roads ascending the Cypress Hills south of Elkwater Lake and Eagle Butte. In southwestern Saskatchewan, the best exposed sections of this formation are along the Frenchman River between Ravenscrag and Eastend, along Adams and Battle Creeks, and along the southwest slopes of Old Man On His Back Plateau. To the east of Eastend, outside of the present study area, Fraser et al. (1935) described its occurrence at Warholes Creek, Rocky Creek, Morgan Creek, Twelvemile Lake, and also farther to the east in the Big Muddy Valley.

The thickness of the formation ranges from 10 to 375 feet. Minimum thicknesses occur on Ravenscrag Butte and along Frenchman River in Saskatchewan. The maximum observed thicknesses occur south of Elkwater Lake, Alberta. In secs. 13, 14, and 24, tp. 8, rge. 3, W. 4th Mer. Russell and Landes (1940) and Crockford (1951) described a thickness of 204 feet, but suggested a total thickness of 225 to 250 feet. However, according to the writer's observations, the formation is 375 feet

thick, one and half miles to the east along Highway 48, in secs. 18 and 19, tp. 8, rge. 3, W. 4th Mer. The thickness of the formation in this area will be discussed later with the heavy mineral studies.

Age and Correlation of the Frenchman Formation

The presence of *Triceratops* fauna indicates that the Frenchman Formation is correlative with the Hell Creek beds of Montana, the typical Lance of eastern Wyoming, and the upper part of the Edmonton Formation of central Alberta (Russell, 1948). Beds near the top of the St. Mary River Formation may be correlative with the Frenchman (Fraser *et al*. 1935).

Berry (1935) recorded the following flora from the formation in the Cypress Lake area:

Aralia notata
Juglans rugosa
Euonymus xantholithensis (?)
Pterospermites penhallowi
Ficus ceratops
Rhamnus cleburni
Fraxinus leii
Viburnum asperum (?)
Ginkgo adiantoides

Among the nine species, *Ficus ceratops* and *Rhamnus cleburni* do not range up into the Ravenscrag Formation. *Ficus ceratops* is characteristic of the Lance Formation. Berry considered the presence of these two species to be sufficient evidence that the Frenchman and Lance Formation are of the same age.

Edmonton Formation

Selwyn (1874) introduced the name "Edmonton Beds" to describe the coal bearing strata exposed in the vicinity of the city of Edmonton. Later Tyrrell (1886) used the term "Edmonton series" to describe non-marine beds exposed along the Red Deer River. Allan and Sanderson (1945) carried out more detailed studies of these beds and named them the Edmonton Formation.

The formation consists of fresh and brackish water, grey coarse to fine grained bentonitic to calcareous sandstone, siltstone, bentonitic shale, bentonite, ironstone nodules and coal beds. A widespread light grey tuffaceous unit 2 to 10 inches thick called the Kneehills Tuff by Sanderson (1931) forms a reliable stratigraphic marker.

The formation conformably overlies the marine Bearpaw shale, the boundary rising stratigraphically toward the east. The boundary between the Edmonton and the overlying Paskapoo Formation was placed at the top of the "big seam" (now known as the Ardley coal seam) along the Red Deer Valley by Tyrrell (1887). Elsewhere it is usually taken at the base of the first massive non-bentonitic brown weathering sandstone. Allan and Sanderson (1945) and Lerbekmo (1964) considered this contact to be disconformable, whereas Campbell (1962) thought it to be conformable. Rutherford (1947), Russell (1950), Tozer (1953), Ower (1958) and Elliott (1958) believed it to be conformable at some places and disconformable at others.

The thickness of the formation ranges from 1,000 to 1,200 feet in the central Alberta Plains and thickens rapidly westward toward the Foothills.

In the Red Deer Valley area Allan and Sanderson (1945) made a threefold division of the Edmonton Formation into lower, middle and upper Members. The Lower Member lies above the Bearpaw Shale and its top is marked by the

Drumheller marine tongue. The Middle Member lies between the Kneehills Tuff and the Drumheller marine tongue which is marked by the occurrence of _Corbicula occidentalis ventricosa_. The Upper Member lies between the Kneehills Tuff zone and the overlying Tertiary Paskapoo Formation.

Ower (1960) after examining the surface sections and well logs of this formation in central Alberta divided it into five members lettered A to E. Member A plus the lower part of Member B are equivalent to the Lower Edmonton. The Upper part of B and Members C, D, are equivalent to the Middle Edmonton. Member E is equivalent to Upper Edmonton.

Age and Correlation of the Upper Edmonton Formation

Sternberg (1947) found that the Kneehills Tuff marks a clear break in the dinosaur fauna of the Edmonton Formation, only _Triceratops_, _Tyrannosaurus_, _Ankylosaurus_, and _Thescelosaurus_ are found above the tuff bed. Bell (1947) identified and divided into two sub-floras the flora of the Edmonton Formation, one occurring above the Kneehills Tuff, the other below. _Filicites knowltoni_, _Carpolithus ceratops_, _Anona robusta_, and _Fraxinus leii_ occurring above the Kneehills Tuff are the diagnostic forms in the Lance Formation, and two of these, _Carpolithus ceratops_ and _Fraxinus leii_ also occur in the Frenchman Formation. According to the Lexicon of Geologic Names of Alberta (1960), "The Edmonton Formation is correlative with the Blood Reserve and the St. Mary River Formations of the southern plains. The lower part of the Willow Creek Formation is possibly correlative with the Edmonton Formation. The Edmonton is also correlative with the Eastend, Whitemud, Battle, and Frenchman Formations of the Cypress Hills; and the Fox Hills, and the Lance Formations of

Montana. In the foothills of the mountains Edmonton equivalents are represented by the upper part of the Wapiti and Brazeau groups".

Cogenetic biotite and sanidine from a bentonite in the Pembina(Ardley) seam at Whitecourt (200 to 300 feet above the Kneehills Tuff) have yielded ages of 63 and 64 million years respectively (Folinsbee et al. 1961). Sanidine from the Upper Ardley coal seam of the Red Deer River valley yielded an age of 63 million years (Shafiqullah, 1963).

It is concluded that the Upper Edmonton Member is correlative with the Frenchman and Lance Formations and represents latest Cretaceous time.

CHAPTER THREE

MECHANICAL ANALYSIS

The size of clastic particles is related to the dynamic conditions of transportation and deposition. Quantitative expression of size frequency distributions should provide clues to the interpretation of depositional environments.

Fourteen sandstone samples from the Frenchman Formation and nine from the Upper Edmonton Member were mechanically analyzed to compare alleged environment sensitive size distribution parameters with published data, and to see if any differences between the two formations were suggested. Differences in degree and kind of cementation required a variety of disaggregation techniques. Size analysis was carried out by sieving combined with the settling velocity differentiation using the pipette method. Details of procedures are described in Appendix B.

Results

Cumulative curves for the twenty-three samples were drawn on arthmetic paper using the phi notation for grain size (dia. mm. = $2^{-Ø}$). The values of Ø 5, Ø15, Ø25, Ø50, Ø75, Ø84, and Ø95 (table 2) were obtained directly from the cumulative curves to calculate the following statistical parameters: average size, sorting, skewness and kurtosis. The cumulative curves and the formulae for calculation of the parameters are shown in Figure 3(1-2) and Appendix B.

Average Size

The "average" grain size of the samples has been obtained from three different measures, namely, the medium and two graphic approximations of the

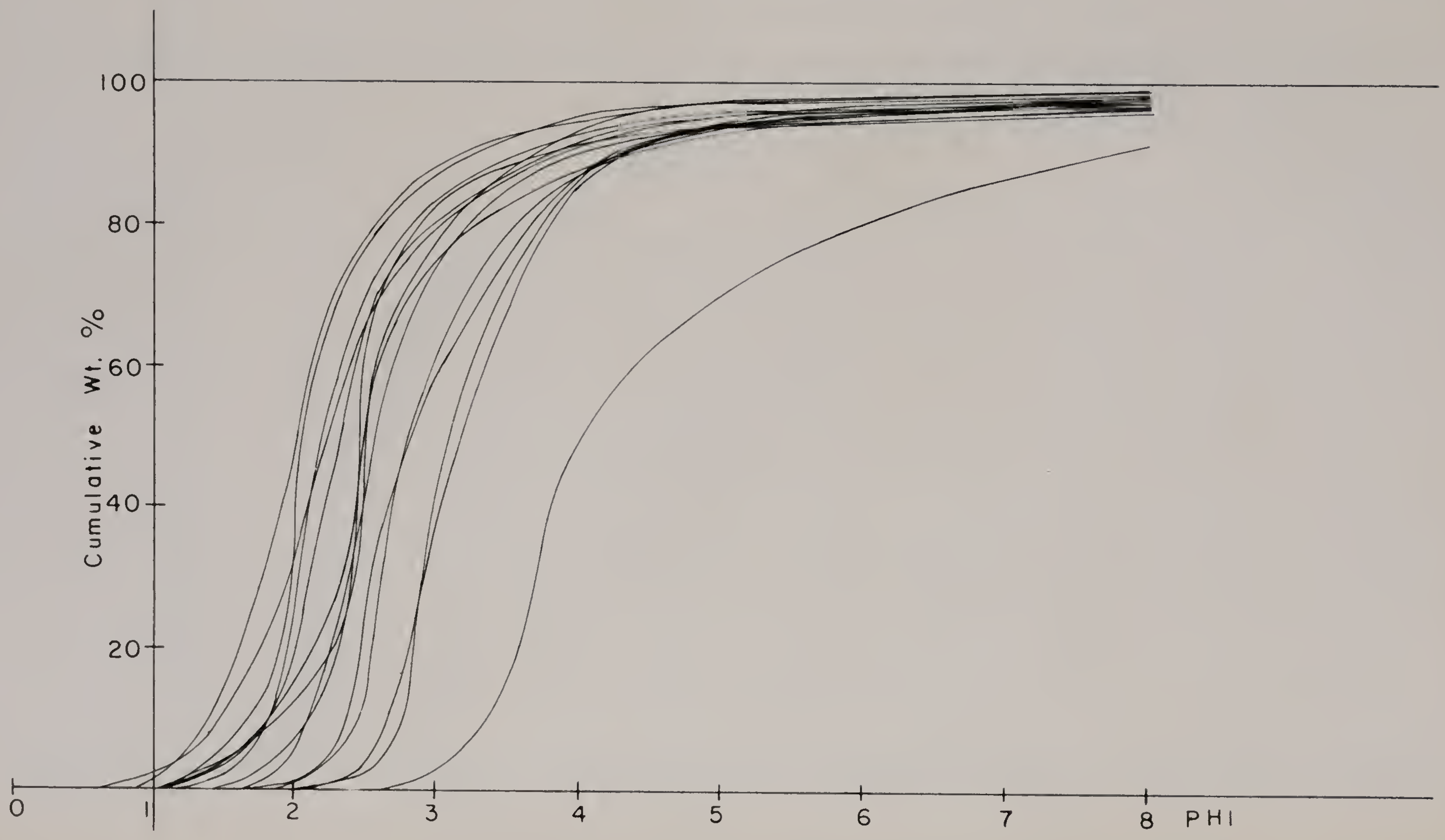


Figure 3-1. Size distribution in Frenchman sandstones.

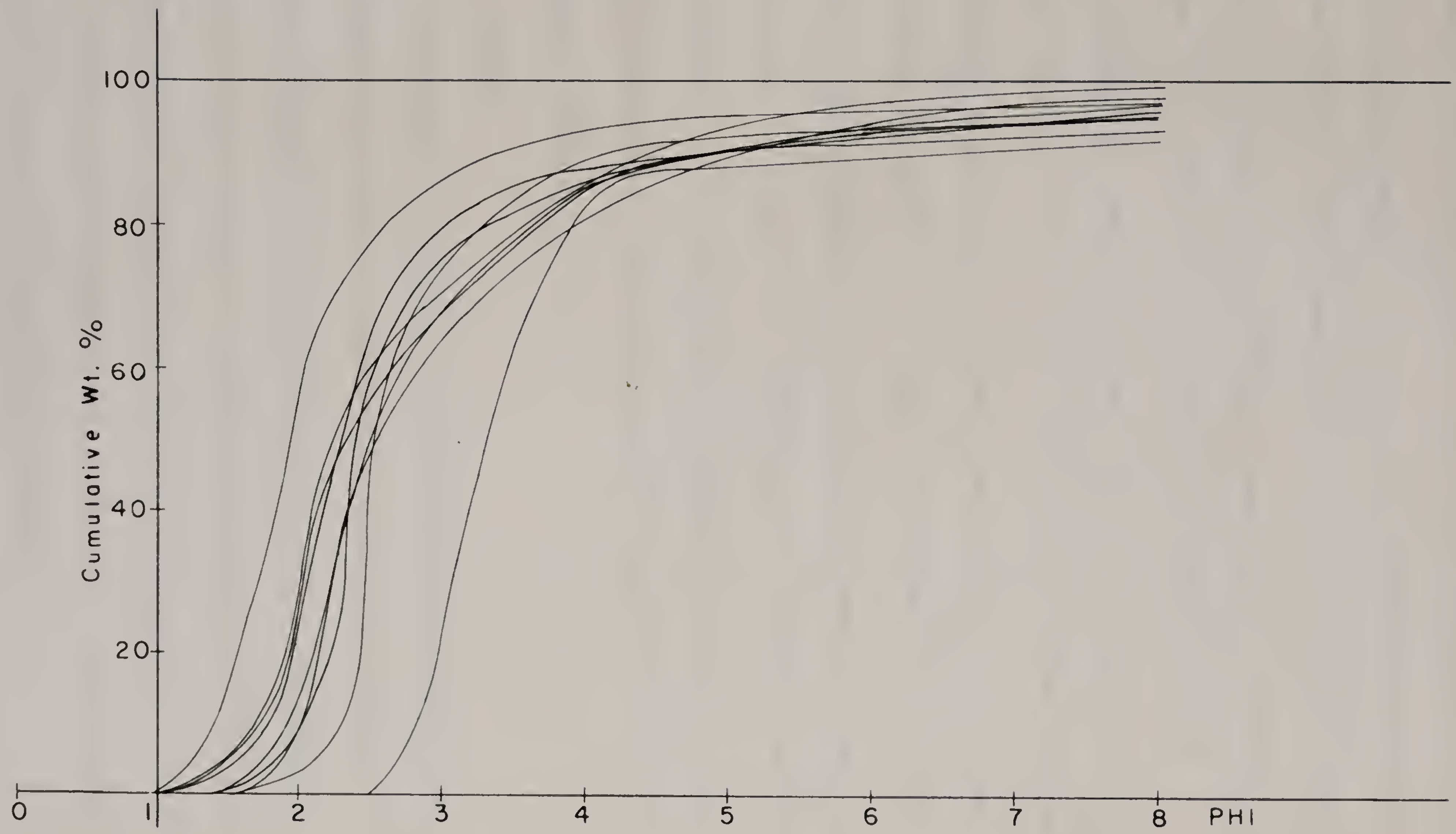


Figure 3-2. Size distribution in Upper Edmonton sandstones.

mean suggested by Inman (1952) and Folk and Ward (1957) and referred to here as Inman mean and graphic mean. The values of the three different measures are tabulated for comparison (Table 3). Inman's mean invariably shows a larger value than the other two measures. The values of the two different means are consistently higher than those of the medium. This indicates that the samples are positively skewed.

The graphic mean has been used in this study to compare the average size range because it corresponds very closely to the mean as computed by the method of moments, and gives a better overall representation of grain size. The graphic means of nine samples from three sections of the Upper Edmonton Formation are fairly similar. The variability is somewhat greater in the Frenchman Formation. In particular, the sample from Ravenscrag Butte is finer (4.68Ø) than those from the other sections of the Frenchman Formation. The average value of 2.82Ø (0.14 mm) for the graphic means of the Frenchman sandstones is slightly higher than the value of 2.75Ø (0.15 mm) for Upper Edmonton sandstones.

Sorting

The measure of uniformity of the samples has been obtained from two different parameters, the graphic standard deviation σ_G (Inman, 1952) and the inclusive graphic standard deviation σ_I (Folk and Ward, 1957). According to Friedman (1962), Inman's measure is reliable for measuring the sorting of moderate to poorly sorted sandstones, whereas that of Folk and Ward appears to be more satisfactory for overall measures of sorting characteristics and provides a good correlation with the standard deviation computed by the method of moments.

Inclusive graphic standard deviation always shows a higher value than graphic standard deviation in the sample studied (Table 3.) The σ_I values of the Edmonton Formation range from 0.63Ø to 1.61Ø whereas those for the Frenchman

Formation range from 0.88Ø to 1.95Ø . These values are typical of fluvial sands. For example, the σ_I values of a Brazos River bar range from 0.40Ø to 2.58Ø (Folk and Ward, 1957). According to Folk and Ward's verbal classification, most of the samples from the Frenchman Formation are moderately sorted whereas those from the Upper Edmonton are poorly sorted.

Skewness

The degree of distortion from symmetry of the size frequency curve has been determined from two different measures, graphic skewness SK_G (Inman, 1952) and inclusive graphic skewness SK_I (Folk and Ward, 1957). The SK_I values are used in the discussion because these values cover not only the central portion but also the tails of the curve. The tails of the skewed curve are probably the most important parts for interpreting depositional environment. Friedman (1961) pointed out that winnowing in a beach environment causes a lack of tail at the fine grained end whereas unidirectional flow such as river transportation may be responsible for the fine-grained tail and therefore positive skewness of river sands.

Of 23 samples, from the Frenchman and Upper Edmonton Formations, 22 are strongly positively skewed; the remaining one (from the Frenchman Formation) is fine skewed based on Folk and Ward's verbal limits. Positive skewness may be indicative of channel environment.

Kurtosis

Kurtosis is the degree of peakedness, or the ratio of sorting in the central part of the curve to the sorting in the tails. Folk and Ward's measure (KG) were calculated. Using Folk and Ward's verbal notation, samples from the Upper Edmonton and Frenchman Formations range from leptokurtic to extremely leptokurtic, but most samples are very

leptokurtic. For plotting graphs, the distribution of graphic kurtosis, K_G has been nomalized by using the transformation $K_G' = K_G / (K_G + 1)$.

Size Parameter Charts

Four size parameters, mean, sorting, inclusive grpahic skewness, and graphic kurtosis were plotted against each other in pairs in order to compare the size parameters of the Frenchman and Edmonton Formations, and are shown in figures 4-1 to 4-6. In general the size parameters of the sandstones of the two formations are similar. However, two scatter plots, namely, mean size versus sorting (Figure 4-1) and skewness versus sorting (4-4) show slightly different fields, for the sandstones of the Edmonton Formation and those of the Frenchman. These separations are related to the differences in sorting between the Edmonton and Frenchman sandstones. The similarity of the other size parameters suggests that the slight differences in sorting are related to different energy conditions of the transporting agent in a similar depositional environment. A noticeable feature of scatter plots of the Frenchman and Edmonton sandstones is the similarity to the scatter plots of samples from a bar in the Brazos River (Folk and Ward, 1957) which are included for comparison (Figure 4). The plot of skewness versus sorting of the samples studied falls in the river sand field shown by Friedman (1961, p. 520) as opposed to beach sands. The general similarity of the size parameters of the samples studied to those of recent river sands corroborates other evidence that the Frenchman and Upper Edmonton sandstones were formed in a fluvial environment.

Textural Maturity

Folk (1951, 1956) considered that textural maturity is an indication of the physical nature of the depositional environment and the amount of energy input. Folk

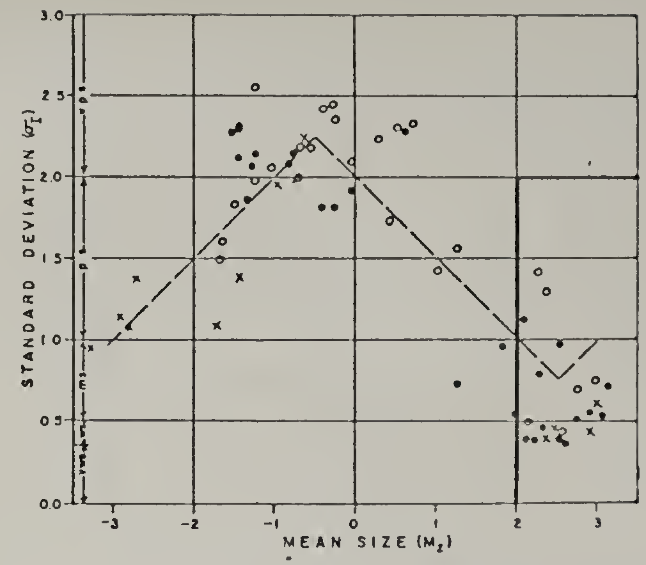


Fig. 10.—Scatter plot of mean size versus standard deviation (sorting). Spot samples shown by filled circles, channel samples by open circles, and special samples by X. Letters along the left margin give verbal limits on sorting: vws, very well sorted; ws, well sorted; ms, moderately sorted; ps, poorly sorted; vps, very poorly sorted. Trend line is discussed in the text.

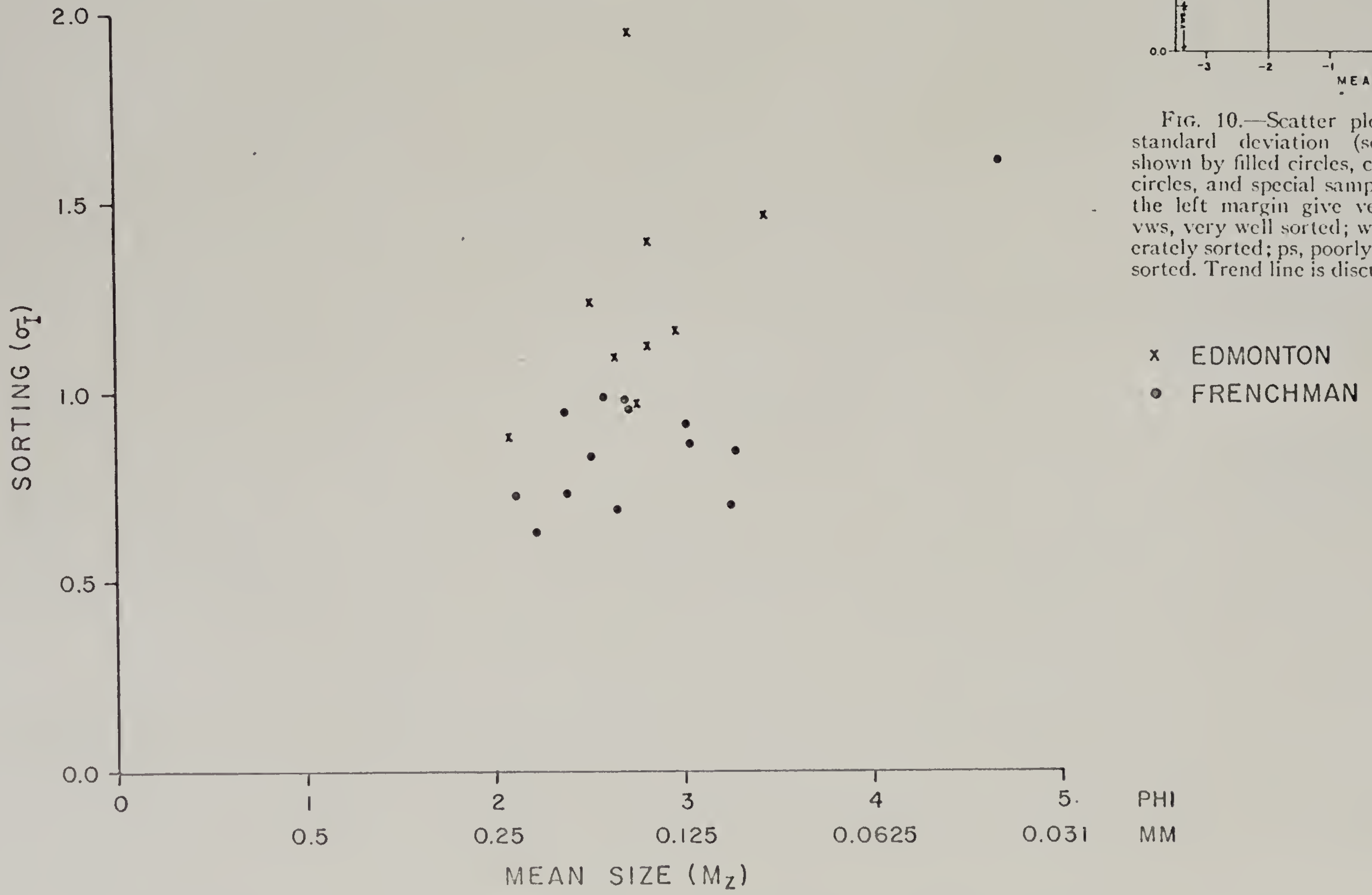


Figure 4-1. Scatter plot of mean size versus sorting. Upper right (from Folk and Ward, 1957) is the scatter plot of Brazos River bar; the square indicates the same range of grain size parameter as the samples studied.

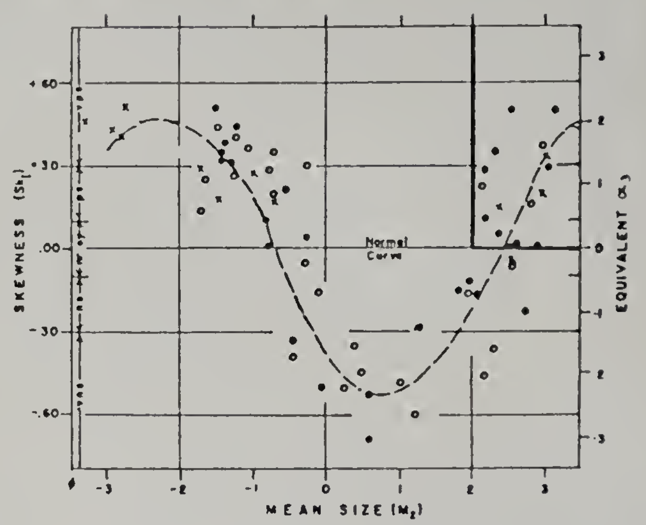
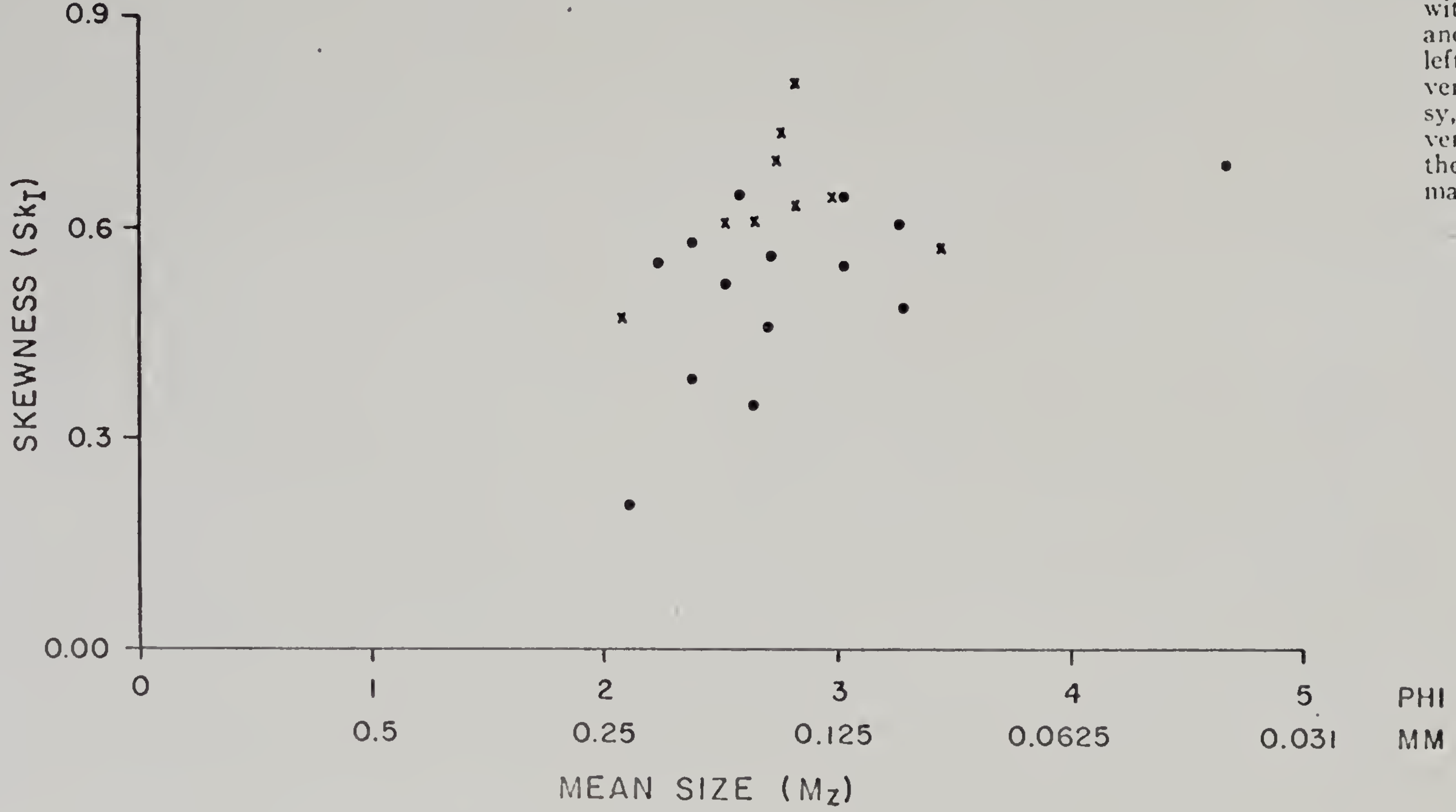


FIG. 12.—Scatter plot of skewness versus mean size. Spot samples shown by filled circles, channel samples by open circles, and special samples by X. The trend is markedly sinusoidal, with nearly equal numbers of positive-skewed and negative-skewed samples. Letters along the left margin give verbal limits for skewness; vns, very negative-skewed; ns, negative-skewed; nr sy, near-symmetrical; ps, positive-skewed; vps, very positive skewed. Equivalent α_3, based on the method of moments, is shown along the right margin.



x EDMONTON
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Figure 4-2. Scatter plot of skewness versus mean size. Upper right (from Folk and Ward, 1957) is the scatter plot of Brazos River bar; the square indicates the same range of grain size parameter as the samples studied.

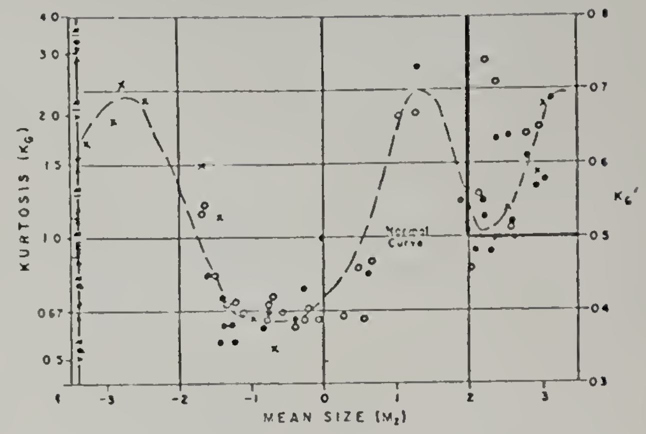


FIG. 13.—Scatter plot of kurtosis versus mean size. Spot samples shown by filled circles, channel samples by open circles, and special samples by X. The trend is complex. Letters along the left margin give verbal limits on kurtosis; vpk, very platykurtic; pk, platykurtic; mk, mesokurtic; lk, leptokurtic; vlk, very leptokurtic; elk, extremely leptokurtic. Points are actually plotted using the transformation $K_{G'}$ shown along the right margin; equivalent K_G is shown at left.

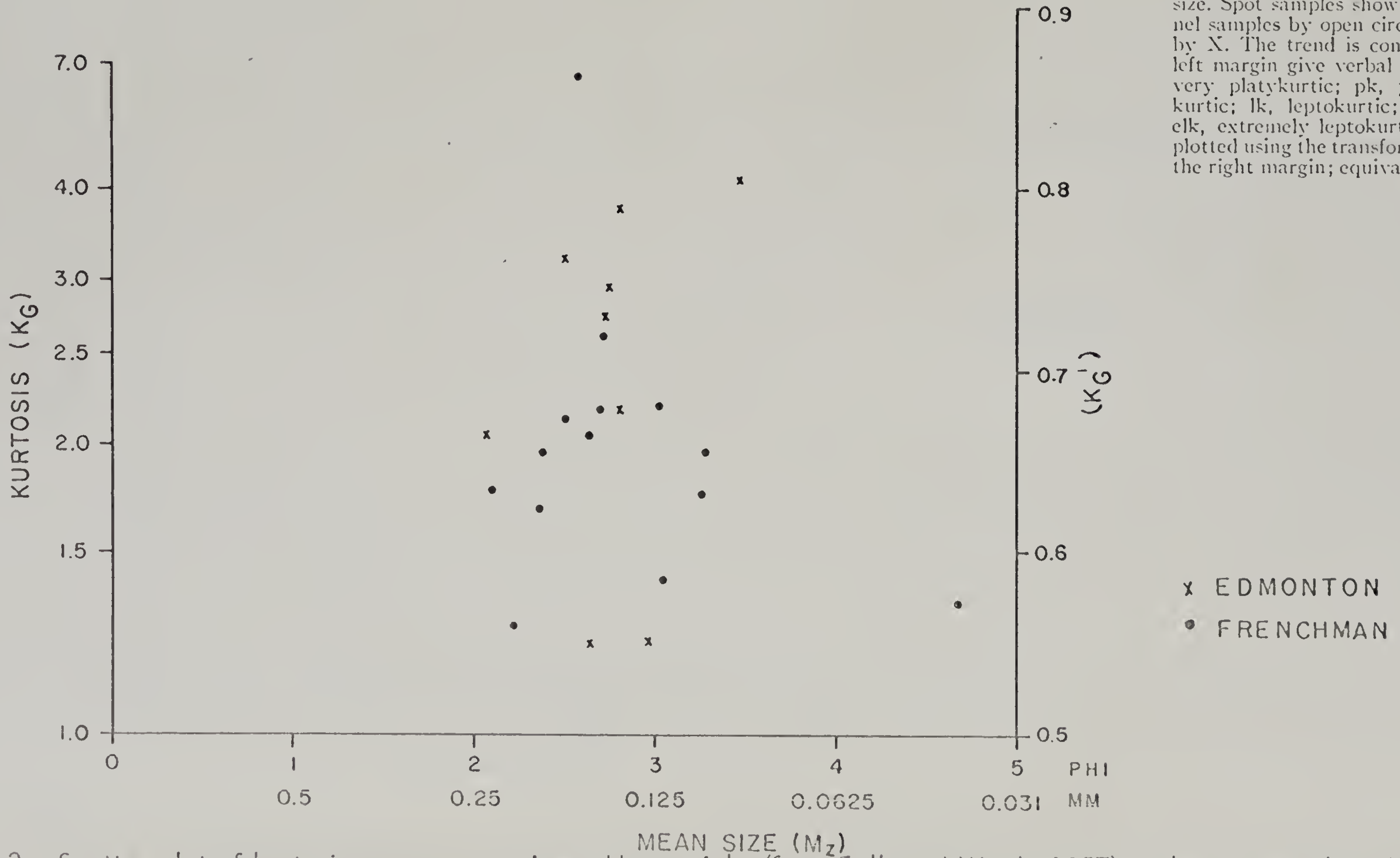


Figure 4-3. Scatter plot of kurtosis versus mean size. Upper right (from Folk and Ward, 1957) is the scatter plot of Brazos River Bar; the square indicates the same range of grain size parameter as the samples studied.

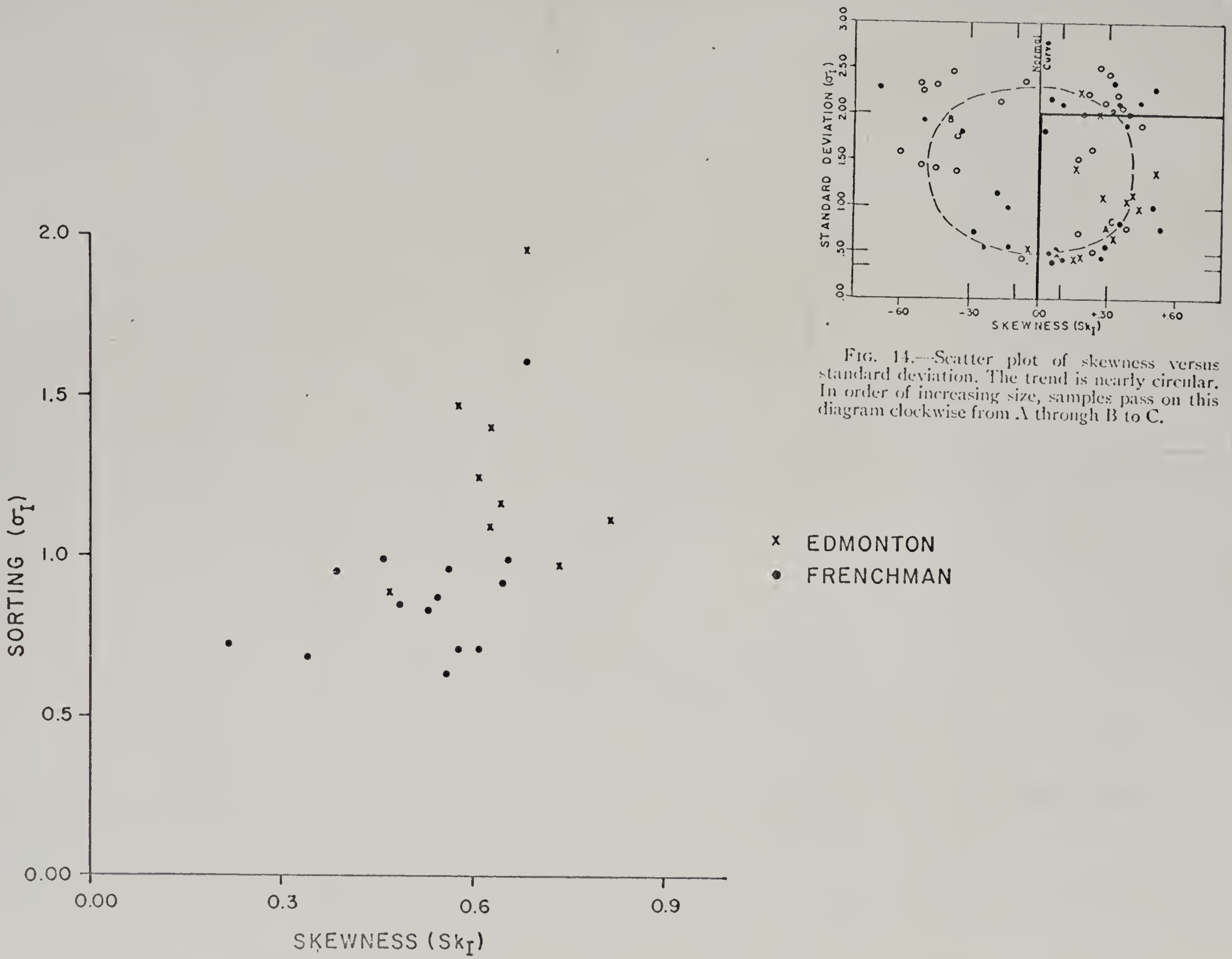
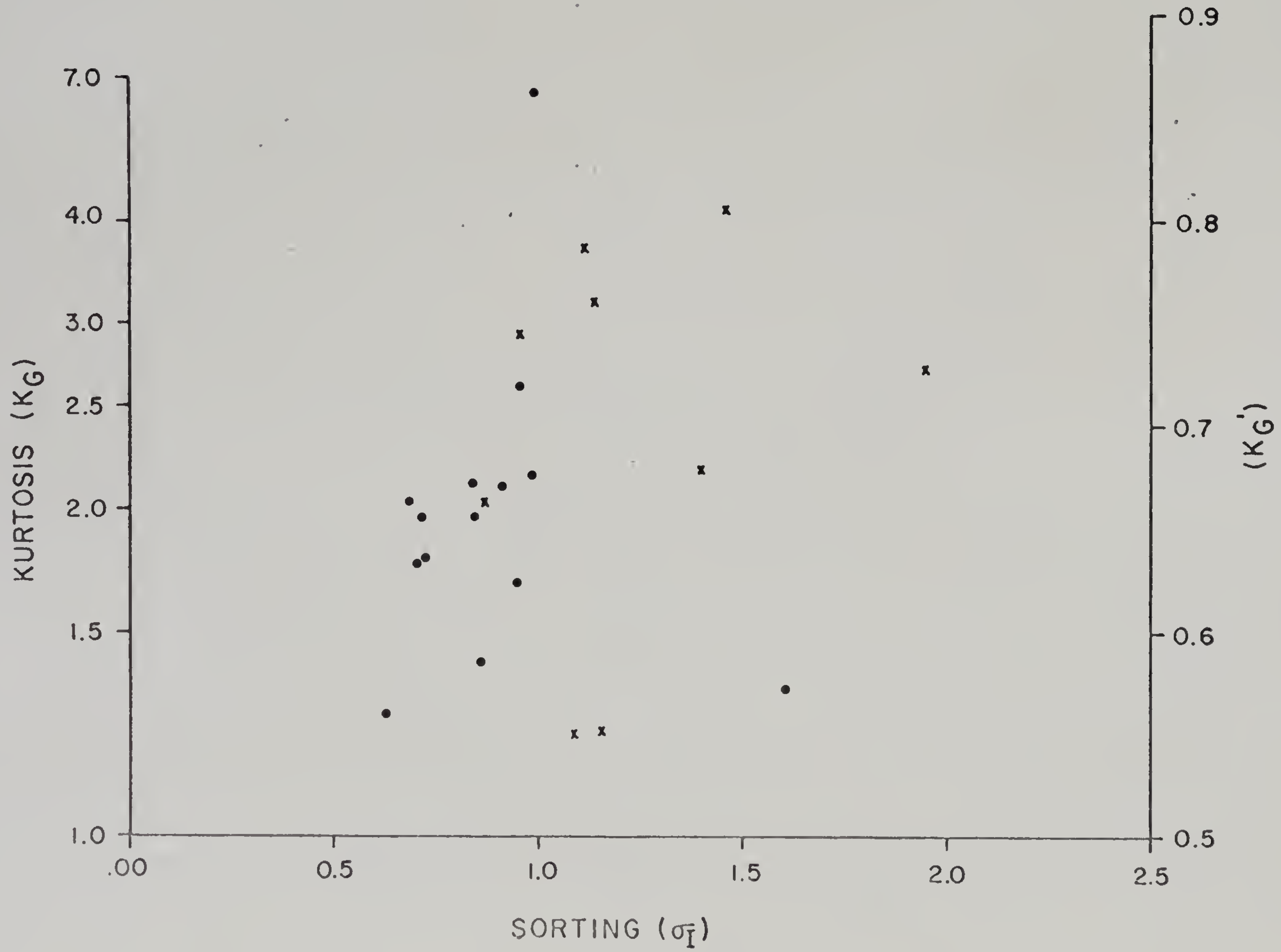


Figure 4-4. Scatter plot of skewness versus sorting. Upper right (from Folk and Ward, 1957) is the scatter plot of Brazos River bar; the square indicates the same range of grain size parameter as the samples studied.



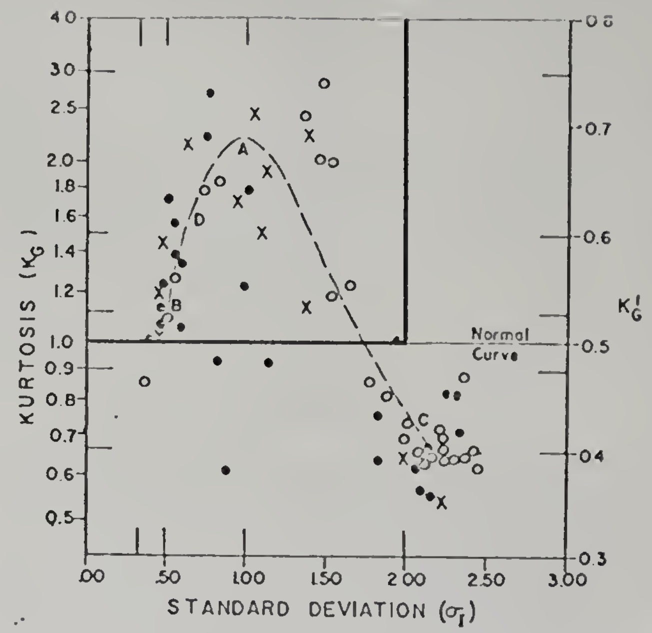
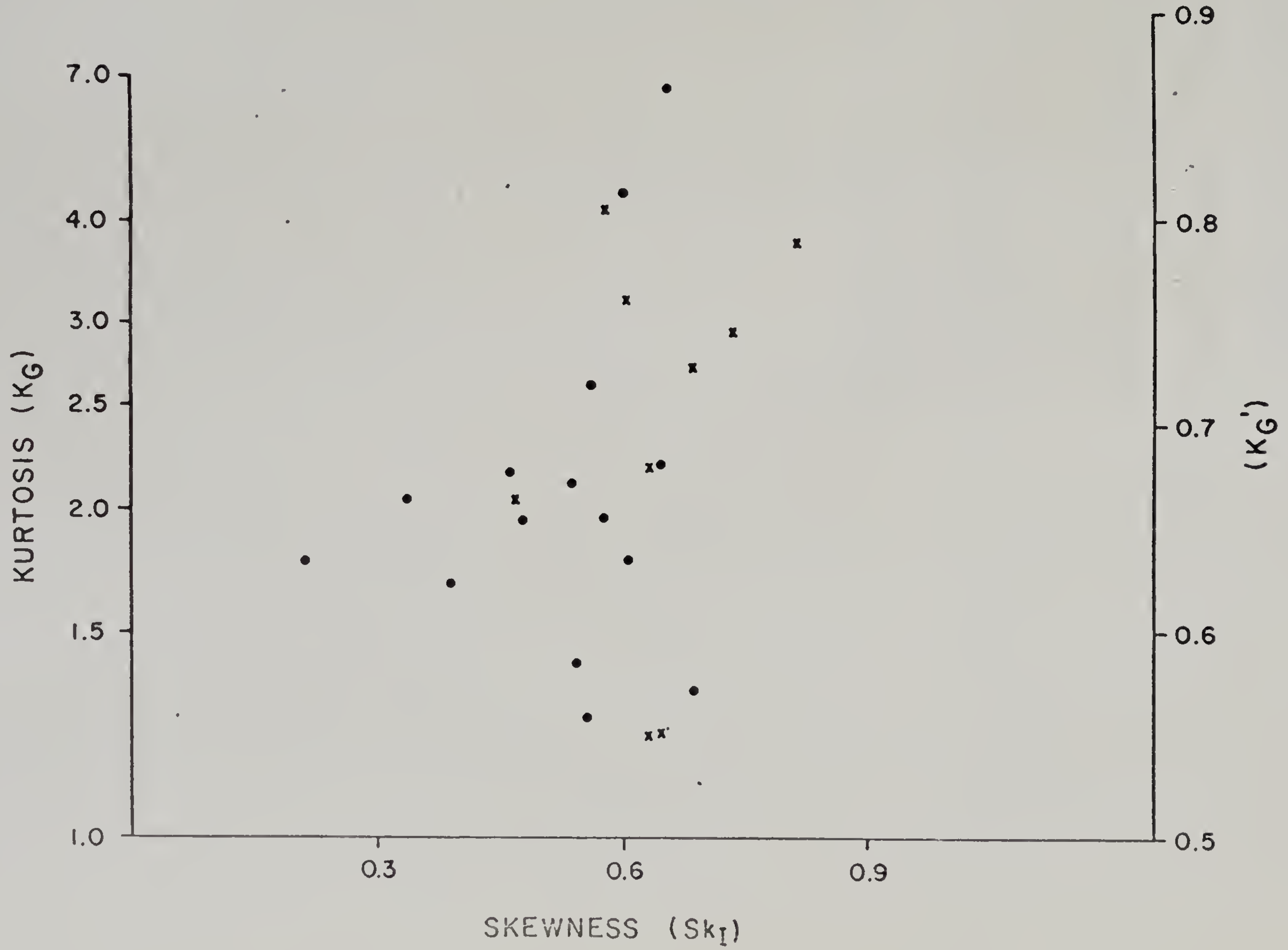


FIG. 15.—Scatter plot of kurtosis versus standard deviation. In order of increasing size, samples follow a regular progression on this diagram, from silty sands (A) to pure sands (B) to slightly gravelly sands (A again), to subequal mixtures of sand and gravel (C). As the gravel content increases, the changes are gone through in reverse, first travelling back to A (gravels with a little sand) and ending at D (nearly pure gravels). A sample of pure gravel would plot approximately at B, just as the samples of pure sand. If one mode is dominant and the other very subordinate, analyses plot at A; if both modes are nearly equal, the analysis plots at C.

Figure 4-5. Scatter plot of kurtosis versus sorting. Upper right (from Folk and Ward, 1957) is the scatter plot of Brazos River bar; the square indicates the same range of grain size parameter as the samples studied.



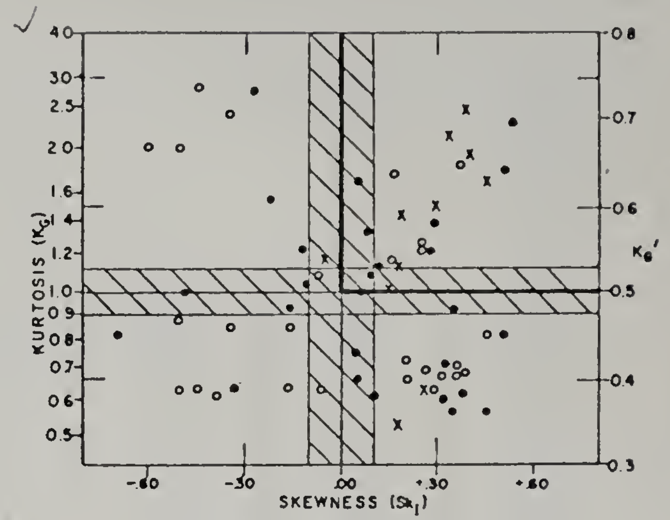


FIG. 16.—Scatter plot of skewness versus kurtosis. Areas here defined as within the range of the normal curve are shown by diagonal-line patterns; only 3 out of the 65 analyzed samples were normal with regard to both skewness and kurtosis. The wide range in skewness and kurtosis values is due to the wide separation between the modes and the ineffective sorting of the depositional environment.

x EDMONTON
• FRENCHMAN

Figure 4-6. Scatter plot of skewness versus kurtosis. Upper right (from Folk and Ward, 1957) is the scatter plot of Brazos River bar; the square indicates the same range of grain size parameter as the samples studied.

defined four stages of textural maturity :

1. Immature stage - sediment contains more than 5 percent detrital clay grains are poorly sorted and angul ar.
2. Submature stage - sediment contains less than 5 percent clay; grains are poorly sorted and angular.
3. Mature stage - sediment contains no clay ; grains are well sorted and subangular.
4. Supermature stage - sediment contains no clay ; grains are well sorted and well rounded.

In this study, based upon the amount of clay, degree of sorting and rounding of the grains, the sandstones from the Upper Edmonton and Frenchman Formations belong to the submature to immature stages of Folk's classifications.

TABLE 2

SIZE DATA FROM CUMULATIVE CURVES

Formation	Sample Number	Ø 5	Ø 16	Ø 25	Ø 50	Ø 75	Ø 84	Ø 95
Frenchman Formation	5039	1.57	2.01	2.24	2.49	2.99	3.61	5.45
	5040	1.60	2.14	2.36	2.51	2.92	3.29	4.32
	5041	2.64	2.83	2.87	3.09	3.59	3.90	5.67
	5042	1.90	2.25	2.36	2.45	2.70	3.08	7.15
	5043	1.22	1.53	1.69	2.10	2.38	2.71	4.16
	5044	1.72	1.91	2.01	2.21	2.66	3.05	4.75
	5045	1.63	1.95	2.05	2.32	2.73	3.28	5.04
	5046	2.26	2.42	2.50	2.84	3.50	3.85	5.71
	5031	1.23	1.65	1.87	2.21	2.27	3.28	4.89
	5405	2.26	2.51	2.57	2.79	3.35	3.76	6.34
	5407	1.44	1.83	1.95	2.04	2.46	2.81	4.03
	5417	2.55	2.75	2.86	3.17	3.64	3.95	6.19
	5409	1.99	2.17	2.30	2.55	2.99	3.41	6.32
	5019	3.16	3.51	3.65	4.02	5.40	6.53	8.86
Upper Edmonton Formation	4716	1.85	2.13	2.27	2.39	2.98	3.75	6.96
	4717	1.60	1.91	2.01	2.30	2.77	3.34	7.52
	4720	1.76	2.05	2.16	2.51	3.36	3.91	7.99
	4721	2.13	2.40	2.45	2.53	3.06	3.54	7.72
	4722	2.68	2.92	3.01	3.32	3.78	4.09	10.53
	5063	1.25	1.49	1.63	1.94	2.39	2.81	4.93
	5064	1.48	1.83	1.96	2.21	3.25	3.89	5.34
	5072	1.52	1.89	1.98	2.34	3.41	3.97	10.92
	5073	1.90	2.11	2.17	2.54	3.56	4.26	6.07

* values are given in Ø

TABLE 3

STATISTICAL SIZE PARAMETERS

Formation	Sample Number	Average Size			Sorting		Skewness		Kurtosis	
		Median (Ø50)	Graphic Mean (MZ)	Inman Mean	σ_G	σ_I	SK_G	SK_I	K_G	K_G'
Frenchman Formation	5039	2.49	2.70	2.81	0.80	0.98	0.400	0.462	2.120	0.679
	5040	2.51	2.64	2.71	0.57	0.69	0.356	0.343	1.991	0.665
	5041	3.09	3.27	3.36	0.53	0.71	0.514	0.608	1.725	0.633
	5042	2.45	2.59	2.66	0.41	0.99	0.518	0.654	6.332	0.863
	5043	2.10	2.11	2.12	0.59	0.73	0.033	0.216	1.746	0.635
	5044	2.21	2.39	2.48	0.57	0.73	0.473	0.575	1.910	0.656
	5045	2.32	2.51	2.61	0.66	0.84	0.458	0.529	2.055	0.672
	5046	2.84	3.04	3.13	0.71	0.87	0.412	0.537	1.413	0.585
	5031	2.21	2.38	2.46	0.81	0.95	0.312	0.388	1.666	0.624
	5405	2.79	3.02	3.13	0.62	0.92	0.552	0.646	2.143	0.681
	5407	2.04	2.22	2.32	0.49	0.63	0.571	0.552	2.073	0.559
	5417	3.17	3.29	3.35	0.60	0.85	0.300	0.479	1.912	0.656
	5409	2.55	2.71	2.79	0.62	0.96	0.387	0.563	2.572	0.720
	5019	4.02	4.68	5.02	1.51	1.61	0.662	0.680	1.334	0.571
Upper Edmonton Formation	4716	2.39	2.75	2.94	0.81	0.97	0.679	0.733	2.950	0.746
	4717	2.30	2.51	2.64	0.71	1.24	0.454	0.608	3.193	0.761
	4720	2.51	2.82	2.98	0.93	1.40	0.505	0.631	2.127	0.680
	4721	2.53	2.82	2.97	0.57	1.12	0.771	0.813	3.756	0.789
	4722	3.32	3.44	3.50	0.58	1.47	0.316	0.576	4.174	0.806
	5063	1.94	2.08	2.15	0.66	0.88	0.318	0.471	1.984	0.664
	5064	2.21	2.64	2.86	1.03	1.09	0.631	0.626	1.226	0.550
	5072	2.34	2.73	2.93	1.07	1.95	0.551	0.687	2.694	0.729
	5073	2.54	2.97	3.18	1.07	1.16	0.600	0.646	1.229	0.551

* Average size and sorting values are given in Ø

TABLE 4

TEXTURAL MATURITY

	Sample Number	Percent clay size	Sorting σ_I	Textural Maturity
Frenchman Formation	5039	2.38	0.98	submature
	5040	1.71	0.69	"
	5041	3.14	0.71	"
	5042	4.31	0.99	"
	5043	1.21	0.73	"
	5044	2.53	0.73	"
	5045	3.25	0.84	"
	5046	2.64	0.87	"
	5031	3.02	0.95	"
	5405	3.30	0.92	"
	5407	2.29	0.63	"
	5417	2.01	0.85	"
	5409	2.81	0.96	"
	5019	8.46	1.61	Immature
	Average	3.08	0.89	Submature
Upper Edmonton Formation	4716	3.46	0.97	Submature
	4717	3.79	1.24	"
	4720	5.15	1.40	Immature
	4721	5.32	1.12	"
	4722	8.85	1.47	"
	5063	2.82	0.88	Submature
	5064	1.46	1.09	"
	5072	6.74	1.95	Immature
	5073	1.60	1.16	Submature
	Average	4.35	1.25	Submature

CHAPTER FOUR

PETROGRAPHY

Introduction

The point count method was used to analyze twenty-one thin sections, twelve from the Upper Edmonton Member and nine from the Frenchman Formation. Four hundred points per thin section were identified and classified as quartz, rock fragments, feldspar, matrix or cement (Table 5) . Quartz and rock fragments were further subdivided into genetic types. Iron, clay, silica, carbonate, and dolomite cements were recorded separately. The percentages of quartz, K-feldspar and Na-feldspar were calculated from counts made on a stained "grain slide".

The mounts made for staining were prepared from the same samples from which thin sections were made. K-feldspar, Na-feldspar and quartz grains between 0.5 mm and 0.088 mm were separated from the disaggregated sample using the Frantz Isodynamic Magnetic Separator. The separated grains were mounted in Lakeside 70, etched with HF acid fumes for 30 seconds and stained with Sodium Cobaltinitrite solution. After this treatment potash feldspars stain yellow whereas sodic-lime feldspars appear milky white from the etching, and quartz grains are not affected. Two hundred grains were counted to obtain the proportions of quartz, potash feldspar and sodic-lime feldspar.

Essential Components

Essential components are mineral constituents of a sandstone which are necessary to its classifications. The averages for the essential components of the Upper Edmonton sandstones when re-calculated to 100 percent are 26 percent quartz, 52 percent rock fragments and 22 percent feldspars. For the Frenchman Formation the figures are

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

27 percent quartz, 49 percent rock fragments and 24 percent feldspars.

Quartz

Six varieties of quartz, namely, common, metamorphic, sedimentary, volcanic, composite quartz and metaquartzite fragment were differentiated on the base of external and internal morphology and extinction characteristics.

Common quartz is the most abundant variety and is a single crystal unit which shows straight to slightly undulose extinction (less than 5°). The degree of undulose extinction is a function of the amount of strain present in the grain. These grains are angular to subangular and variable in shape and size. Most are nearly free from inclusions but very small, dusty appearing inclusions, larger liquid inclusions, acicular needles, zircon and muscovite crystals were observed in a few grains. Common quartz grains are probably derived from igneous, metamorphic and sedimentary rocks. The lack of definite characteristics to indicate genetic relationship make it impossible to assign common quartz grains to any particular source rocks, although pre-existing sedimentary rocks are probably the major source.

Metamorphic quartz is a single crystal unit characterized by strong undulose extinction. The presence of strained quartz grains in both igneous and metamorphic rocks indicates that undulose extinction does not rigidly characterize the genetic relationship.

Rounded to well rounded quartz grains are designated as sedimentary quartz and suggest several cycles of erosion. Because of the high resistance of quartz to abrasion, grains derived from a second cycle of erosion may retain considerable angularity. The difficulty in recognizing reworked angular sedimentary quartz probably yields too low a percentage of this type.

Volcanic quartz is characterized by well developed bipyramidal crystal faces

with rounded corners (Plate II-2). These grains are free from inclusions and show sharp extinction. In very fine sandstones, the identification of volcanic quartz is difficult because of poor preservation of crystal faces.

Polycrystalline quartz grains composed of two or more quartz crystal units showing different optical orientation have been subdivided into composite quartz and metaquartzite fragments (Hubert, 1960). A composite quartz grain consists of an aggregate grain of two or more separately extinguishing units separated by smooth, non-sutured boundaries. The composite quartz variety includes Folk's (1961) schistose metamorphic quartz and recrystallized metamorphic quartz grains with straight to slightly undulose extinction. Schistose metamorphic quartz grains are characterized by well oriented mica flakes between the internal crystal units. Recrystallized metamorphic quartz is more common than schistose metamorphic quartz in the rocks of this study.

A metaquartzite fragment consists of two or more crystal units that are separated by sutured boundaries. Individual crystal units show strong undulose extinction. These grains are generally elongate in shape and sometimes enclose a few inclusions.

Rock Fragments

Lerbekmo (1963) subdivided rock fragments into four genetic types, namely, sedimentary, metamorphic, volcanic and a fourth group of uncertain genetic affinities. This classification was used in the present study.

The sedimentary rock fragments are subdivided into chert and mudrock (including siltstone). Chert is the most abundant rock fragment in samples from the Upper Edmonton and Frenchman Formations. Two different types of chert, one composed of microcrystalline quartz and the other of chalcedony (Folk and Weaver, 1952) have been observed in this study. The most abundant type, microcrystalline quartz, appears as an

aggregate of equant microcrystalline interlocking crystals showing slight undulose extinction. Occasionally, microcrystalline quartz is transitional into, or in sharp contact, with coarse quartz. Only a few chalcedonic quartz grains showing radiating fibers occur in samples.

Mudrocks are fine grained argillaceous rock fragments which are usually a mixture of clay and silt. Most of these rock fragments lack any apparent degree of parallel orientation of constituent minerals. These rock fragments were probably derived from well indurated mudstones and shales. Clastic carbonate rock fragments have been observed in a few samples of the Frenchman and Upper Edmonton Formations. Because of the difficulty in differentiating clastic carbonate from calcite cement in carbonate cemented sandstones, clastic carbonate grains were included under carbonate cement. Most of the clastic carbonate grains are rather dusty looking compared with carbonate cement, but this feature is not always diagnostic because of the presence of cloudy calcite cement. Sometimes a very fine rim of dusty material which developed between the clastic carbonate grains and the carbonate cement is helpful in differentiating the two types of carbonate.

Metamorphic rock fragments are common in all the samples studied. Most of the grains are low grade metamorphic rock fragments, such as argillites, slates and metasiltstones. Argillites are defined as showing some recrystallization of phyllosilicates, mainly chlorite; but lacking the strong preferred orientation of a slate. Metasiltstones are characterized by recrystallized silt-size quartz with or without a lesser amount of finer matrix (Lerbekmo, 1963). Varieties of metamorphic rock fragments were counted together because of the difficulty in differentiating between them. Rocks of uncertain genetic affinities were also included under metamorphic rock fragments in

this study.

Volcanic rock fragments are very abundant in the samples studied. These rock fragments are characterized by the presence of lath-like feldspar crystals(Plate II-3). Volcanic rock fragments lacking feldspar microlites are difficult to distinguish from argillaceous rock fragments, however, a pale to moderate brownish colour in transmitted light is more common in volcanic rock fragments than in the argilleous type.

Feldspar

Several varieties of potash feldspar, namely, orthoclase, sanidine and microcline were observed in all the samples studied. Orthoclase grains, usually untwinned, are often cloudy and sometimes show randomly distributed sericite flakes. Sanidine grains are less altered than orthoclase grains and are free from inclusions. The difference of axial angle between orthoclase ($2V = 70^{\circ}$) and sanidine ($2V = 10^{\circ}$) is a more reliable distinguishing feature than the above observation. Microcline grains showing polysynthetic twinning are present, but are less than one percent in each thin section.

Plagioclase grains are common in all the samples, and fresh and altered plagioclase grains are present. Most of the altered grains show numerous sericite flakes scattered randomly and sometimes developed along cleavage planes. One or two grains of zoned plagioclase were observed in a few slides. Myrmekitic texture showing vermicular forms is present in a few grains of orthoclase and plagioclase (Plate II - I).

Sodium feldspar are more abundant than potassium feldspars in the Frenchman Formation whereas this relation is reversed in the Edmonton Formation (Figure 5). The lower content of volcanic rock fragments in the Frenchman Formation as compared with the Upper Edmonton indicates that plagioclase derived from a volcanic origin is

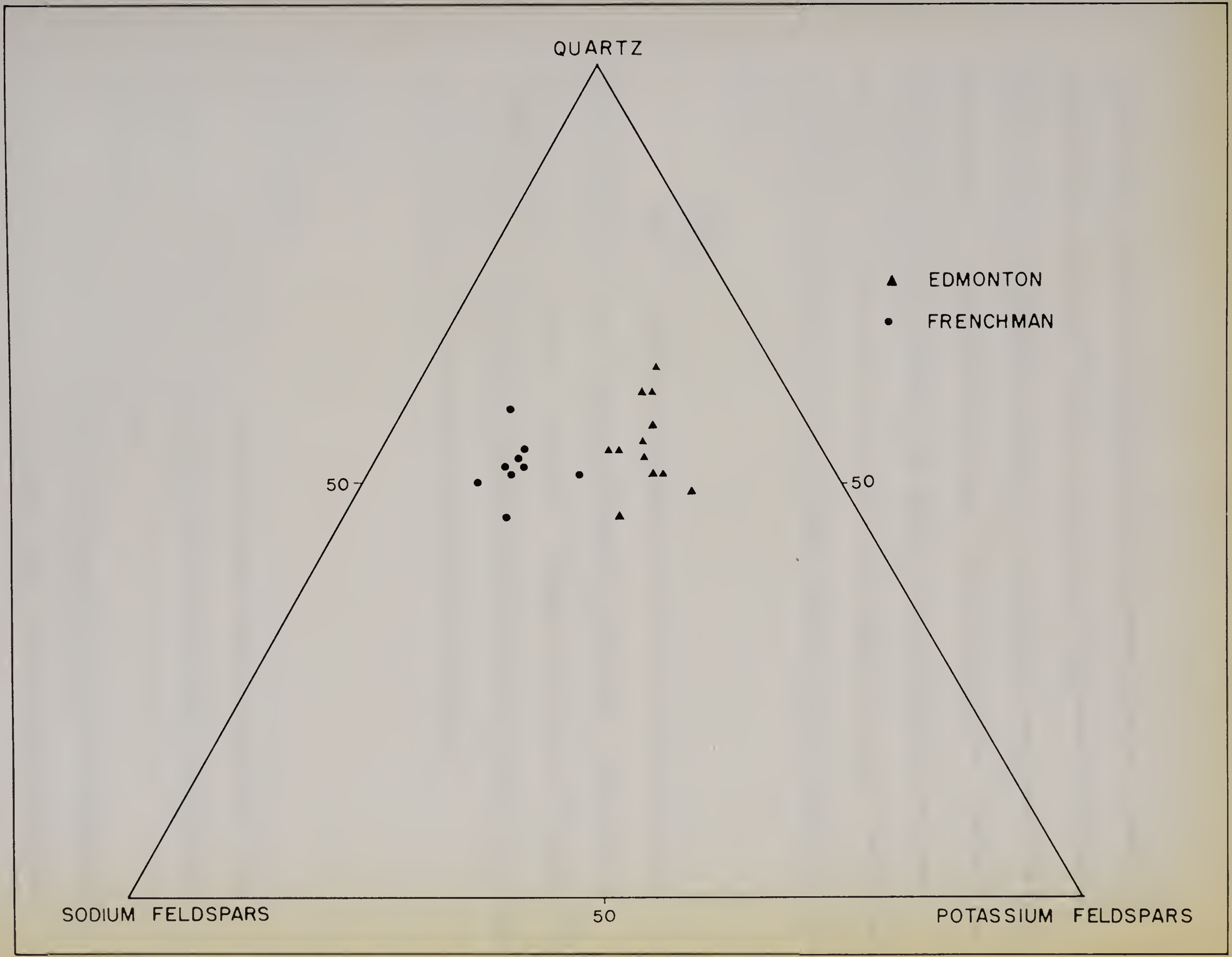


Figure 5 Diagram showing the difference in sodium and potassium feldspar content between Frenchman and Upper Edmonton sandstones.

not the cause of enrichment of plagioclase in the Frenchman Formation. Instead, the writer considers that rocks in the main source area had a high content of plagioclase, such as is found in basic igneous rock areas. The abundance of hornblende in the Frenchman Formation, to be described later, tends to confirm this conclusion. Similarly, the high content of potassium feldspar in the Edmonton may be explained by the presence of potassium rich rocks in source area, such as acidic igneous rock types. The abundance of biotite in the heavy mineral suite of the Upper Edmonton Formation supports this conclusion.

Matrix

Matrix includes all detrital materials smaller than 0.03 mm (Doty and Hubert, 1962) which fill the interstices between the larger grains. Compositions of matrix are clay, mica, feldspar, and quartz. The types of clay have not been identified. Its percentages in Upper Edmonton sandstones range from zero to 17 percent of the samples by volume whereas those for Frenchman range from zero to 24 percent.

Cements

Calcite Cement

Calcite cement is volumetrically a very important constituent of these sandstones, but the amount and distribution of the calcite cement is variable from section to section in these formations.

On the basis of the amount and distribution, the calcite cementation can be subdivided into three types (Waldschmidt, 1941). In the first type the carbonate cement is minor and widely separated. A second type shows segregated larger masses of carbonate cement. A third type is characterized by the carbonate cement

forming a continuous mass in which the sand grains are imbedded. In the sandstones of the third type, most of the sand grains are separated and appear to float in a mass of calcite cement. This type of cementation is more common than the other types in this study.

The most obvious explanation for the formation of the third type of cementation is the replacement of sand grains by calcite (Plate I-4). Several stages in the replacement of quartz, feldspar and rock fragments are evident. Replacement of the grains proceeds from the outer edge of the grains inward, advantage being taken of existing cracks and cavities (Hatch, Rastall and Black, 1938; Krynine, 1940; Swineford, 1947; Pettijohn, 1949; Nicholas, 1956). The outlines of grains which have been completely replaced may be observed, and it is conceivable that the process of replacement might continue until calcite alone remains.

Another factor is the tendency of calcite to force particles apart during the course of crystallization (Swineford,1947; Gilbert, 1947; Carozzi, 1960). This was observed in thin sections showing grains having been forced apart along incipient fractures and the fragments scattered and rotated so that they are no longer in optical continuity with each other (Plate I-1, 2,).

Waldschmidt (1941) assumed that the composition of a sandstone composed of a large proportion of calcite cement and a small proportion of detrital grains was the result of the consolidation of a mass of sandstone containing mechanically admixed limestone grains, and was accomplished by solution of the limestone followed by its reprecipitation as calcite cement before appreciable migration. A mechanically mixed sand composed of quartz grains and calcareous fossil fragments can be converted in a similar manner into a highly calcareous sandstone.

Two types of calcite cement, granular and fibrous, were observed in this

study. Granular cement as defined here includes equant and irregular shape crystals. Fibrous cement has well developed fibre texture perpendicular to the surface of detrital grains (Plate I-6).

Silica Cement

Silica cement is present in a few samples of the Frenchman and Upper Edmonton units. It occurs as overgrowths in optical continuity with detrital quartz grains (Plate I-1, 5). According to Lerbekmo (1961), quartz overgrowths can be differentiated from the nucleus by one or a combination of the following criteria : the nucleus has more inclusions than the overgrowth; a thin line of impurities marks the boundary between detrital quartz and cement; the detrital grain shows straining whereas the overgrowth does not.

The quartz overgrowth in this study are identified by the presence of a thin line of impurities between the detrital grain and overgrowth. Silica cement in the Frenchman and Upper Edmonton sandstones does not exceed one percent of the sample by volume. Most of the overgrowths are irregular in shape and seldom have well developed crystal faces because of growth interference of adjacent grains.

Clay Cement

Authigenic clay has been observed in a few samples of Frenchman and Upper Edmonton sandstones which lack calcite cement. It occurs as thin films on the detrital grains and forms less than seven percent of any sample (Plate II-5). These thin, colourless birefringent coatings are similar to the montmorillonite described by Carrigy and Mellon (1964). Chlorite and kaolinite have been identified in thin sections but other types of clay have not been positively identified under the microscope.

Iron-oxide cement

Iron-oxide cement occurs in a few samples of Frenchman and Upper Edmonton sandstones. It forms a coating on sand grains and sometimes fills the interstices between grains. Iron coated sand grains are common in both calcareous and non-calcareous cemented sandstones. It generally forms less than 3 percent by volume of the sample, except in sample 5065 where it reaches 11 percent.

Dolomite cement

The presence of authigenic dolomite in sample 6058a from the Upper Edmonton Member has been identified by staining method (Friedman, 1959). It forms 17 percent of the sample. The authigenic dolomite occurs as rhomb-shaped crystals in the calcite cement or as vein material between the clastic grains and calcite cement (Plate I-7). The dolomite is brownish yellow especially in the margin of the crystals, whereas calcite cement is colourless. During point counting idiomorphic crystal shape and colour were used to differentiate dolomite from calcite cement.

Classification

Klein (1963) and McBride (1963) have reviewed a considerable number of field and laboratory classifications of sandstones which have been proposed. McBride points out that classification schemes of sandstones are devised to approach descriptive and genetic features of a particular rock.

The following criteria have been used to classify sandstones : colour (Lerbekmo, 1962) ; mineralogical composition (Krynine, 1948 ; Folk, 1954 ; Travis, 1955 ; Van Andel, 1958) ; mineralogical and textural maturity (Tallman, 1949; Dapples, Krumbein and Sloss, 1953 ; Gilbert, 1954 ; Bokman, 1955 ;Pettijohn, 1957) and structural, textural

and mineralogical features (Packham, 1954 ; Crook, 1960). The classification scheme proposed by Travis (1955) has been used in this study in order to incorporate data on the abundance of chert, low grade metamorphic rock fragments and volcanic rock fragments and to subdivide rocks with high percentages of these components.

According to the Travis classification, seven of the nine Frenchman sandstone samples studied are lithic sandstones whereas the two remaining samples are rock fragment sandstones (Figure 6). Of twelve samples from the Upper Edmonton, six are rock fragment sandstones, four are lithic sandstones and two are transitional between lithic and rock fragment sandstones.

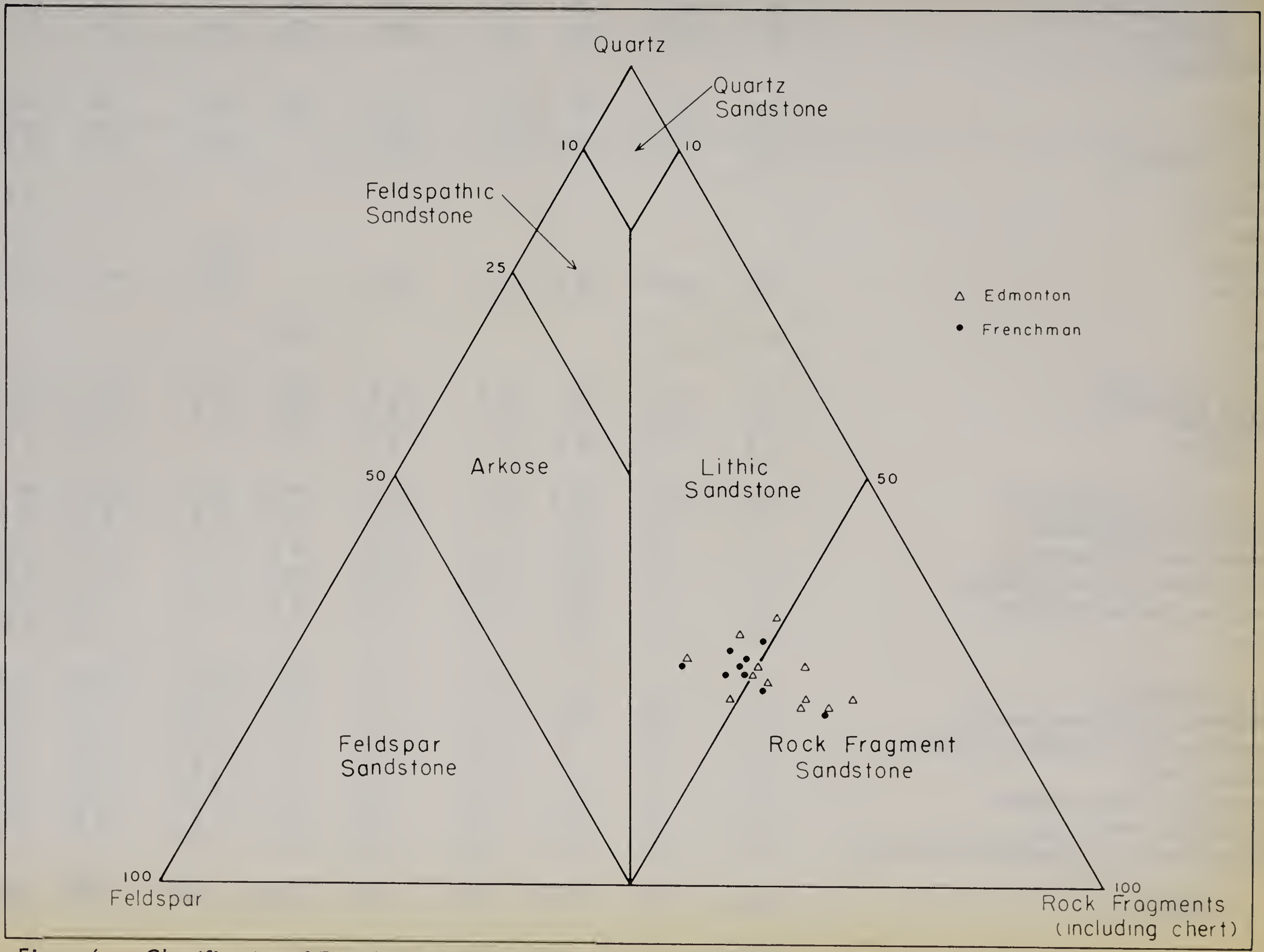


Figure 6 Classification of Frenchman and Upper Edmonton sandstones based on proportion of essential components. (triangular diagram after R. B. Travis, 1955)

Table 5-1

COMPOSITION OF FRENCHMAN SANDSTONES

Sample No.	5409	5411	5412	5413	5414	5405	5408	5401	5030
Common quartz (<5° undulatory extinction)	6.8	6.5	5.2	5.5	7.8	7.5	5.5	5.3	8.3
Metamorphic quartz (>5° " ")	3.3	3.0	3.2	3.5	3.8	7.0	1.5	2.5	1.7
Sedimentary quartz (rounded)	2.2	1.2	0.8	1.3	2.0	1.7	2.2	1.2	1.2
Volcanic quartz	0.2	0.2		0.8	0.5		1.0	0.3	1.0
Composite quartz (straight contacts)	3.3	1.8	1.8	2.2	2.0	3.8	4.8	4.0	4.3
Metaquartzite (sutured contacts)	1.2	0.8	0.5	1.0	1.2	1.5	1.5	1.5	0.5
TOTAL QUARTZ	17	13.5	11.5	14.3	17.3	21.5	16.5	14.8	17.0
Chert	14.8	9.5	8.0	7.3	9.5	8.2	4.8	9.2	4.8
Mud rock (includes Siltstone)	7.5	5.7	5.7	2.2	2.5	9.8	2.7	2.5	5.0
Total Sedimentary rock fragments	22.3	15.2	13.7	9.5	12.0	18.0	7.5	11.7	9.8
Metamorphic rock gragments	13.5	5.8	6.0	5.5	5.0	9.8	7.0	5.8	7.7
Volcanic rock fragments	7.7	5.2	4.8	6.7	10.2	8.5	11.8	8.2	13.2
TOTAL ROCK FRAGMENTS	43.50	26.2	24.5	21.7	27.2	36.30	26.3	25.7	30.7
K-Feldspar	4.8	3.3	5.0	5.2	3.0	6.0	4.7	4.3	5.0
Plagioclase	11.2	10.0	6.2	11.3	8.8	12.5	9.8	9.0	11.5
TOTAL FELDSPARS	16	13.3	11.2	16.5	11.8	18.5	14.5	13.3	16.5
Matrix	18	4.2				23.7			
Calcite	4.5	42.8	52.8	47.5	43.7		42.2	46.2	33.0
Dolomite							0.5		
Silica									
Iron-oxide									2.8
Clay	1								
TOTAL CEMENTS	5.5	42.8	52.8	47.5	43.7		42.7	46.2	35.8
TOTAL	100	100	100	100	100	100	100	100	100
Classification :									
Quartz %	21:	26	24	27	30	28	29	27	26
Rock Fragments %	60	49	52	42	49	48	46	48	47
Feldspar %	19	25	24	31	21	24	25	25	27
TOTAL	100	100	100	100	100	100	100	100	100

Table 5-2

COMPOSITION OF UPPER EDMONTON SANDSTONES

Sample No.	5063	5064	5065	5073	5074	5076	4716	4717	4720	4721	4709	5068a
Common quartz (<5° undulatory extinction)	8.8	6.8	10.3	10.0	7.8	8.0	8.8	11.8	6.5	10.5	14.3	7.5
Metamorphic quartz (>5° " ")	2.3	1.0	0.2	2.0	2.5	0.2	3.5	2.0	1.0	2.8	1.3	2.5
Sedimentary quartz (rounded)	1.0	1.7	1.3	0.5	0.5	1.0	0.7	0.3	1.7	0.7	0.7	0.5
Volcanic quartz	0.5	0.7	0.7	0.7	1.5	0.5	1.0	0.2	1.5	1.2	0.5	1.0
Composite quartz (straight contacts)	5.7	2.8	2.3	5.5	3.0	2.8	4.0	3.5	2.8	4.8	3.5	2.3
Metaquartzite (sutured contacts)	1.5	0.7	0.7	0.5	1.7	1.8	0.8	0.7	2.0	1.8	0.2	0.5
TOTAL QUARTZ	19.8	13.7	15.5	19.2	17.0	14.3	18.8	18.5	15.5	21.8	20.5	14.3
Chert	13.0	10.5	9.0	9.5	8.5	9.3	10.3	7.7	10.8	9.5	10.5	6.0
Mud rock (includes Siltstone)	9.2	6.5	6.5	6.8	4.0	4.2	6.2	5.5	6.7	8.5	5.5	5.0
Total Sedimentary rock fragments	22.2	17.0	15.5	16.3	12.5	13.5	16.5	13.2	17.5	18.0	16.0	11.0
Metamorphic rock fragments	13.8	8.2	7.0	6.5	6.2	9.7	10.2	9.5	8.5	12.5	7.0	3.7
Volcanic rock fragments	17.0	11.3	10.2	13.2	6.8	17.0	11.5	15.0	12.0	10.7	8.0	6.8
TOTAL ROCK FRAGMENTS	53.0	36.5	32.7	36.0	25.5	40.2	38.2	37.7	38.0	41.2	31.0	21.5
K-Feldspar	7.7	8.0	10.0	11.5	12.5	6.5	7.8	9.8	7.8	10.0	7.8	6.7
Plagioclase	5.0	5.3	8.8	7.0	5.8	5.7	4.5	6.7	5.2	9.0	3.7	4.0
TOTAL FELDSPARS	12.7	13.3	18.8	18.5	18.3	12.2	12.3	16.5	13.0	19.0	11.5	10.7
Matrix	9.3	5.7	1.5	15.5			2.0	4.5	3.2	17.0		
Calcite	0.2	30.3	20.8	1.2	39.2	33.3	28.5	22.5	30.3	0.5	35.8	36.8
Dolomite												16.7
Silica	0.7	0.2		0.5			0.2	0.3				
Iron-oxide	0.8	0.3	10.7	2.8							1.2	
Clay	3.5			6.3						0.5		
TOTAL CEMENTS	5.2	30.8	31.5	10.8	39.2	33.3	28.7	22.8	30.3	1.0	37.0	53.5
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100
Classification :												
Quartz %	23	22	23	26	28	22	27	25	23	27	33	31
Rock Fragments %	62	57	49	50	42	60	55	52	57	50	49	46
Feldspar %	15	21	28	24	30	18	18	23	20	23	18	23
Total	100	100	100	100	100	100	100	100	100	100	100	100

CHAPTER FIVE

HEAVY ACCESSORY MINERALS

Preparation of Samples

Both poorly consolidated and well indurated sandstones were analyzed for heavy minerals. Strongly indurated samples were coarse crushed in a jaw crusher followed by disaggregation with motar and pestle; poorly consolidated sandstones were disaggregated with motar and pestle alone.

The crushed samples were sieved to obtain about 70 gm of minus 80 plus 230 mesh fraction for the heavy mineral separation. Heavy minerals were separated using tetrabromethane (S. G. = 2.95) and standard separating funnels.

Heavy minerals separated from four samples contained large amounts of carbonate which was removed by heating in 10 percent HCl. One sample contained about 80 percent of siderite which was removed by boiling in a 30 percent HCl solution with stannous chloride.

Using an Otto type microsplitter, a small sample of the heavy mineral fraction was taken for a permanent mount in aroclor (Refractive index = 1.66) on a millimeter grid slide.

Method of Study

Heavy minerals were separated from the outcrop samples of the Upper Edmonton, Frenchman and Ravenscrag Formations from the twelve sections used in this study. Following is a tabulation of the number of samples used for heavy mineral study from each section:

Upper Edmonton Member sections

Scollard Canyon .... 5 samples

Wood Lake .... 5 "

Breda .... 5 "

Trenville .... 2 "

Frenchman Formation sections

Ravenscrag Butte .... I sample

Ravenscrag .... 8 samples

Old Man On His Back Plateau .... 6 "

Adams Creek .... 3 "

Elkwater, Highway 48. .... 9 "

Elkwater, Camp Ground Rd .... 8 "

Elkwater, Scenic Road .... 2 "

Eagle Butte .... 4 "

Ravenscrag Formation sections

Ravenscrag Butte .... 9 samples

Adams Creek .... 5 "

Elkwater, Highway 48 .... 8 "

Elkwater, Scenic Road .... I sample

The stratigraphic positions of the samples in each section are shown in figures 7-I through 7-I2.

The heavy mineral grains were identified under the petrographic micro-

scope by their optical properties. the determinations of relative abundance are based on counts of 200 non-opaque mineral grains (excepting biotite) identified on each of the 81 slides studied. The biotite and opaque mineral grains accompanying the 200 non-opaque minerals in the slide were counted without identification of specific opaque minerals. The types of biotite were simply classified as red or brown whereas the opaque minerals were red and black. A further classification of each of the non-opaque minerals was attempted based upon colour and shape. (Tables A-1, -2, -3, -4, -5, -6, -7, -8, -9, -10, and -11).

Description of Non-Opaque Heavy Minerals

Allanite

Allanite is widespread but sporadic in occurrence. The grains are of irregular or prismatic shape, and most show concoidal fracture. The colour is brown with a distinct yellow brown to dark brown pleochroism. Apatite (?) inclusions are occasionally present.

Andalusite

Andalusite is a rare but widespread heavy mineral in the study area. The grains are usually irregular in shape and angular with a concoidal fracture, but a few grains have a prismatic form, and others show some rounding. Some grains show inclusions of small opaque grains,bubbles or apatite .

Apatite

Apatite is very common in all the samples studied. The vertical and lateral distribution of apatite is rather variable. It occurs as rounded anhedral or euhedral grains which are terminated either by the basal pinacoid (0001) or pyramid

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(1011) or both in combination. In the prismatic apatite a ratio of breadth : length is approximately 1 : 2. All the apatite is fresh with no sign of corrosion.

The apatite was classified into colourless and coloured varieties. Most of the grains are colourless and devoid of inclusions. In a few grains, zircon, rutile, apatite, minute cavities or black opaque inclusions occur oriented parallel to the crystallographic C-axis (Plate VIII - 3,4,5, Plate X - 10). The occurrence of coloured apatite, pale brown, dark brown and reddish brown was noted. The dark coloured portion generally forms the core or nucleus of the apatite grain and it is surrounded by light coloured apatite; frequently the coloured part shows faint pleochroism. The boundary between the dark nucleus and the light coloured part of the crystal may be transitional or sharply defined. In most grains, the dark coloured part is elongate parallel to the crystallographic C axis (Plate VIII-1, 2, Plate VI-12). Occurrences of dark coloured apatite have been described in many places in England (Fleet and Smithson, 1928; Groves, 1927; and Simpson, 1933). These writers suggested that coloured apatite may be useful in tracing the source of the detrital grains.

Twinned apatite which shows a definite composition plane have been observed in samples from the Edmonton Formation (Plate VIII - 1, 2).

Chlorite

Minerals of the chlorite group are common and widespread heavy minerals but their occurrence is not continuous. These grains are of irregular, flat, subrounded to rounded shape. The colour is pale green with a slight pleochroism. Two varieties have been distinguished in this study. One variety is characterized by a deep yellowish green or deep green colour, moderate relief, lack of extinction, weak birefringence colours and has dusty inclusions or alteration material frequently associated with it.

This variety possibly includes penninite and clinochlore and is common in the Edmonton Formation. The other variety is characterized by a pale green colour, low relief, is almost isotropic , and lacks pleochroism. This type possibly includes chamosite and is common in the Ravenscrag Formation.

Apatite and small opaque inclusions have been observed in the dark green chlorite. Most of the pale green chlorite grains are free from inclusions. Biotite altering to chlorite has been observed but the time and place of this alteration is not known.

Clinozoisite-Zoisite

Clinozoisite is a common heavy mineral and is present in almost every sample studied. Most of the grains are angular, equidimensional and irregular in shape. No definite crystal habit has been observed, but a few grains show imperfect (100) cleavage. The grains are generally free from inclusions but bubbles and small opaque flecks occur in some grains. A few grains show evidence of corrosion (Plate VI - 16), but this phenomenon is less common than in epidote.

Zoisite is a rare heavy mineral in this study. Because of the small amount, ranging zero to 2.5 percent, and the similarity in chemical and optical properties, zoisite grains have been included with clinozoisite in the graphs.

Epidote

Epidote is a widely distributed and abundant mineral in the Frenchman and Ravenscrag Formations. The presence of this mineral in the Edmonton Formation is very irregular, ranging from zero to 22 percent. The fine silty sandstones from the Frenchman Formation gave the highest concentration of this mineral with a maximum of 52 percent of the heavy fraction in the Ravenscrag Butte section.

Epidote grains are irregular in shape, angular and lack crystal habit. Pleochroism is rather weak but distinctive changing from colourless to yellowish-green. Small opaque inclusions are common.

Some grains show comb shape at the margin of the grain or an irregular hole within the grain as evidence of solution effects (Plate X - 18, Plate VI -17). Strongly corroded cockscomb formsof epidote have been reported in lower tertiary sands in California by Beveridge (1960). This phenomena indicates that epidote is not stable in some intrastratal solutions.

Garnet

Garnet is a very abundant and widespread heavy mineral in the study area. The Edmonton Formation is enriched in garnet (19.5 to 45.5 percent) as compared to the Frenchman and Ravenscrag Formations (1.5 to 33 percent).

Most of the garnets are angular fragments with subconchoidal to cocoidal fracture. A few grains show sharp euhedral (dodecahedron) or subhedral shapes (Plate V - 13, 14). Six colour varieties : colourless, pink, brown, reddish brown, yellow and green were separately counted, but because of the low percentage of the colour varieties other than colourless and pink, other coloured grains were included in the charts with pink grains. Colourless garnet is very abundant in the Edmonton Formation, whereas pink garnet is characteristic of the Frenchman and Ravenscrag Formations.

Bubbles, opaques, dusty specks, needles and unidentified minerals are common inclusions in the garnet, but some grains are free from inclusions. The dusty inclusions tend to form aggregates in the grains and appear as smoky patches. Most of the grains in this study show no evidence of solution effects, but a few grains

show strongly etched surfaces (Plate IX - 16). Co-existence of etched and unetched grains indicates that some varieties of garnet are unstable in alkaline intrastratal solution (Lerbekmo, 1963), but other varieties are stable in the same solution. This available published data on chemical stability of garnet in sedimnets is confusing. However, the presence of angular, fresh garnet indicates that it has undergone only a single cycle of sedimentation.

Hornblende

Hornblende is one of the most abundant and widespread heavy minerals in the Frenchman Formation. The relatively high percentage of hornblende in the Frenchman Formation is a useful criterion to distinguish this formation from the Ravenscrag Formation in this study area.

Hornblende grains are usually elongated cleavage plates with irregular terminations. Etched grains showing the evidence of solution effects have hacksaw or cockscomb terminations (Plate VII - 1, 2). Two subvarieties based on colour, brown and green, were distinguished. Green hornblende is more abundant than the brown variety. Bubbles, opaques and apatite are common types of inclusion. Some grains show a parallel orientation of apatite grains along the cleavage or other crystallographic direction, but inclusions are randomly distributed in most grains.

All the hornblende is fresh and unaltered; grains with hacksaw terminations occur sporadically in the Frenchman Formation, being limited to 30 foot intervals in the Elkwater Camp Ground Road and Ravenscrag sections; the stratigraphic position differs in the two sections. This distribution indicates that etched grains are formed by local intrastratal solutions.

Rutile

Rutile is a common and widespread heavy mineral in the Upper Edmonton and Ravenscrag Formations, whereas it is rare in the Frenchman Formation.

Irregular, stumpy and anhedral grains are common, but a few grains show elongate and prismatic forms. A ratio of length : breadth of 6 : 1 has been attained in some prismatic forms (Plate VIII - 8). "Elbow" twins developed on a face of the dipyramid of the second order (011) have been observed (Plate X - 7). Well developed oblique striations were noted on a few grains (Plate VI - 5). The rutile was classified as either yellow or red. Reddish-brown grains were classified with the red variety. The yellow variety is the most common type and tends to be rounded. Most grains are free from inclusions, but apatite (?) and black opaques have been observed.

Sphene

Sphene is a common and widespread mineral in the samples studied. The following three different shapes have been recognized in this study. (1) Euhedral and broken euhedral grains (Plate V - 8, 12, Plate IX - 17); (2) angular grains with conchoidal fracture and without crystal faces; (3) rounded grains (Plate V - 10, 11). The angular grains indicate a rather short distance of transportation or are possibly of authigenic origin, whereas the rounded grains appear to be second cycle. All the angular grains are fresh and even the rounded grains do not show any evidence of corrosion. The mineral is colourless, pale yellow or light brown; the light brown variety is the most common type in coarser grains. Bubbles, opaques and apatite inclusions have been observed in most of the grains (Plate V - 8, 9, 10, 12).

Tourmaline

Tourmaline is a common heavy mineral in these rocks. In the Edmonton

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[illegible]

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and Frenchman Formations it does not exceed 10 percent of the non-opaque heavy minerals, but it is relatively concentrated in the Ravenscrag Formation, reaching a maximum of 25 percent.

Tourmaline may have a variety of colours, and can also be classified by differences in shape and inclusions.

Three different types based on shape are : (a) prismatic grains terminated by pyramids (Plate VI - 4), (b) irregular grains with angular or smooth surfaces (Plate VIII - 12), (c) well rounded grains (Plate VIII - 13, Plate X - 6). Most of the grains are free from inclusions but bubbles, opaques and zircons have been observed (Plate VI - 3, 4). Because of the wide range in shape and the uncertainty as to the composition of the inclusions, colour alone has been used to classify tourmaline in this study. Six different varieties of tourmaline were recognized : pink, green, brown, blue, yellow and colourless.

Pink tourmaline is more abundant in the Ravenscrag Formation than in the Edmonton and Frenchman Formations. Most grains show prismatic crystal faces with pyramidal terminations, or an irregular shape. Angular fragments and well rounded grains are common. Bubbles and dusty opaque inclusions are fairly abundant, and tend to be concentrated in the centre of the grains. Dichroism is very distinctive from pink to dark green or greenish-black and in a few grains from pink to colourless. Krynine (1946) suggested that pink to greenish black tourmaline is of plutonic origin.

Green tourmaline is another common variety in the Ravenscrag, Frenchman and Edmonton Formations, but it is not as abundant as pink tourmaline. Most grains are free from inclusions but bubbles and "dusty inclusions" have been observed. Change in colour from pale green to dark green is usual.

Brown tourmaline, like the pink and green varieties is widespread. Grains are usually rounded but retain prismatic crystal faces. Inclusions are rather rare. The dichroism is from colourless to pale brown, and from pale brown to dark brown. Krynine (1946) mentioned that this type of grain is derived from granitic rocks.

Blue tourmaline (indicolite) is not abundant and its occurrence is not continuous in any of the sections. Grains are always fragmental and free of inclusions. The dichroism is pale sky blue to dark blue. This type of grain is of pegmatitic derivation and its exclusively fragmental character is accounted for by the breaking of large tourmaline crystals.

Colourless to pale yellow or pale yellow to deep yellow dichroic grains are not abundant in the samples studied. They are free of inclusions and show a range in shape.

Non-dichroic colourless grains with bubble and apatite inclusions are common. Most of the grains are elongate and retain prismatic faces.

Authigenic Tourmaline

Overgrowths on tourmaline have been observed in the Elkwater Highway 48 section of the Ravenscrag Formation (Plate X - 1, 2, 3, 4, 5). These overgrowths are either colourless or pleochroic from pink to green or from pale pink to yellow. They are developed on well rounded grains and form three different types as follows:

1. idiomorphic crystal shape showing prisms terminated by pyramids (Plate X - 1).
2. irregular shape still showing crystal faces (Plate X - 3,5).
3. irregular shape (Plate X - 4).

Most of the overgrowths are free of inclusions but bubbles and dusty

inclusions have been observed (Plate X - 1, 2).

Authigenic growths on tourmaline, similar to type 3, have been described by Alty (1933), Krynine (1946), Gokhale and Bagchi (1959) and Awasthi (1961). They observed that these authigenic growths were developed only on a limited portion of the surface of the grains. According to Alty's (1933) pyroelectric tests, these overgrowths are restricted to the antilogous pole, which is characterized crystallographically by the faces r(1011) and m(1010). In this study the writer noticed that overgrowths are not restricted to certain crystallographical positions, but may grow around the entire margin of the grains.

Krynine (1946) considered that this type of authigenic tourmaline was formed in the sea in a cold water environment, penecontemporaneously with sedimentation. He also mentioned that the overgrowths are identical in their properties throughout the same formation.

The writer has concluded that the authigenic tourmaline found in the Ravenscrag Formation was derived from pre-existing sediment.

This conclusion is based on the following observations.

1. The overgrowths are not identical in their properties (colour and chemical composition).
2. The overgrowths show some rounding, which indicates that they have been transported to their present location (Plate X - 2).
3. This formation was deposited under continental conditions (Furnival, 1946; Russell, 1948).

Tremolite-Actinolite

Because of overlapping characteristics and the resultant difficulty in

differentiating these two members of the amphibole group, tremolite and actinolite are grouped together in this study.

Grains of tremolite-actinolite are rare in the Frenchman and Ravenscrag Formations, and have not been observed in the Upper Edmonton Member in the area studied. They occur as elongated and prismatic forms. "Spine" shaped terminations are more frequently observed in the colourless tremolite than in the pale green actinolite grains contrary to what might be expected. Bubbles and opaque specks are common inclusions in tremolite.

Zircon

Zircon is abundant in all of the samples. Zircon varieties can be classified using inclusions, shape, zoning, idiormorphism and colour.

Inclusions are very common and include rounded or irregularly shaped cavities (some probably filled with gas), liquid, black opaque, euhedral zircon and apatite. Most of the inclusions do not have any orderly arrangement or preferred orientation, but some zircon and apatite inclusions are oriented parallel to the crystallographic C axis (Plate IV - 4).

Grain shape of the zircon shows a gradation from sharp euhedra, through rounded prismatic to well rounded grains lacking crystal faces. Euhedral zircon usually shows a simple combination of prism and dipyramid of the first order (Plate IV - 13), but grains occasionally show the second order pyramids and base (Plate IV - 6, Plate V - 5). No statistical studies of zircon elongation were made in this study, but the most common ratio of breadth : length ranges from 1 : 1 to 1 : 3 and the maximum ratio recorded is 1 : 6 (Plate IV - 1). In the present study shape was used for classifying as follows : (a) angular euhedral grains; (b) rounded subhedral grains;

(c) angular anhedral grains, and (d) rounded anhedral grains.

Water action does not round grains below a certain size (Wyatt, 1954, Hutton, 1952). Wyatt (1954) mentioned that a high degree of rounding may be due to extensive wind transportation, crystallization of zircon as well rounded grains and solution or mechanical granulation during metamorphism. Therefore, rounded zircon is not conclusive evidence for multiple cycle origin. The coexistence of corroded and euhedral crystals may be explained by fluctuation in temperature of magma, corroded types representing early formed grains that were partially reabsorbed when the temperature of the magma was increased, and euhedral forms representing crystallization during subsequent cooling (Spotts, 1962).

Zoning is not a very common feature but it has been observed in a few grains. Outer thin parallel zones enclosing an unzoned central area is the most common type. That is, in most of the zoned zircons, zoning is more apparent near the periphery than toward the centre (Plate V - 1, Plate IX - 4). Another type is a single overgrowth over euhedral zircon (Plate IV - 10).

Twinned zircons have been observed in samples from the Frenchman, Edmonton and Ravenscrag Formations. Twinning on (101) by the normal twinning law shows the knee-shaped form (Plate III - 8, Plate IX - 3). Another common type is the contact twin which shows a definite composition plane (Plate III - 1, 2, 4, 5, Plate IX - 1, 2). Multiple contact twins producing a three euhedra zircon aggregate have also been found (Plate VII - 14). In contact twins of zircon, the crystallographic C axes are parallel.

Outgrowths on zircon were found in the Frenchman Formation. Similar types of outgrowth have been previously described in igneous and sedimentary rocks

(Butterfield, 1936, Smithson, 1937, Poldervaart and Eckelmann, 1955). Smithson(1941) mentioned that outgrowths have developed most frequently in zones where the rare earth mineral monazite appears to have suffered decomposition. On the other hand, if the outgrowths are considered to consist of zircon, it seems necessary to assume that some zirconium bearing mineral has suffered decomposition and that zircon has crystallized at a temperature much lower than that at which it is normally formed.

Composite crystals were observed (Plate III - 3, 10, 12) which are similar in shape to "aggregate crystals" described by Poldervaart and Eckelmann (1955), but differ in their environment of formation. The euhedral grain aggregate (Plate III - 3) indicates that these aggregate crystals have been formed during the crystallization of magma wereas rounded grain aggregate described by Poldervaart and Eckelmann has been formed during the formation of autochthonous granites.

The euhedral zircons are also suggestive of an igneous source. Varieties of zircons characterize different types of igneous rocks. Huang (1958) in his study of Precambrian igneous rocks observed that the zircons in gabbroic rocks are a mixed assemblage of irregular fragments, chips, subrounded and stumpy crystals, in contrast to the euhedral grains found in granitic rocks. The irregular zircon crystal habit in the basic rocks probably has been caused by incomplete growth of the mineral during crystallization.

Colourless and hyacinth zircons are the two most common colour types present. The term hyacinth is used to denote coloured zircons ranging from very pale pink through pink to a deep purple. The relative abundance of colourless and hyacinth zircons varies from one section to another, but colourless zircon is always more abundant than hyacinth. Hyacinth zircon was separately counted and subdivided on shape.

The data indicate that more than 80 percent of the hyacinth zircons are well rounded. This suggests that the grains have passed through several cycles of erosion. Zoning is a more common feature in hyacinth zircon compared with the colourless variety (Plate V - 1). Outgrowth was seen on hyacinths (Plate III - 14, 16), but twins have not been observed in hyacinth zircons.

Tomita (1954) suggested that hyacinth zircons are indicative of Precambrian age based on the period of time needed to produce a colour tint by radio-irradiation.

Other non-opaque heavy minerals

Heavy minerals observed in minor quantities in this study are staurolite, chloritoid, brookite, glaucophane, spinel, pyroxene and barite.

All these heavy minerals, except glaucophane, are present in samples from the Edmonton , Frenchman and Ravenscrag Formations. Glaucophane has been found only in samples from the Frenchman Formation. Because of the difficulty in differentiating spinel from garnet by microscope study alone, the presence of spinel was checked by the immersion method using methylene iodide. Collophane is abundant in a few samples and is areally widespread in the study area. Because of its low specific gravity (2.6 to 2.9), it was not included as a heavy mineral in this study. Barite was abundant in one sample (5410) from the Old Man on His Back Plateau section of the Frenchman Formation. Local enrichment, irregular shape and angularity indicate that this barite is authigenic in origin.

Biotite

Biotite is much more abundant and widespread in the Edmonton Formation than in the Frenchman and Ravenscrag.

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[illegible]

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[illegible]

[illegible]

[illegible]

[illegible]

Irregular angular cleavage flakes are usual, but some grains show a hexagonal outline. Two colour varieties, brown and red, were differentiated. Brown biotite is always more abundant than the red variety. Inclusions noted are bubbles, opaques, zircon and needle shaped rutile (?) crystals.

Opaque heavy minerals

Red or black colour in reflected light was the basis for classifying the opaque minerals accompanying the 200 counted non-opaque minerals. The kinds of opaque minerals were not counted separately, but hematite, leucoxene, magnetite, ilmenite and pyrite were identified.

Regional and Stratigraphic Distribution of Heavy Minerals

General Statement

The average weight percentages of total heavy minerals in samples from the Edmonton, Frenchman and Ravenscrag Formations are respectively 0.73, 1.16, and 0.44 percent of the detrital components. The percentages of the individual non-opaque heavy minerals except biotite from different localities and stratigraphic units is presented in tables 7 and 8. The abundances of biotite and opaque heavy minerals are expressed as the number accompanying 100 non-opaque minerals in the slide. The three most characteristic heavy minerals of each of these formations are : garnet, apatite and zircon in the Upper Edmonton Formation; hornblende, epidote, and garnet in the Frenchman Formation; epidote, garnet and tourmaline in the Ravenscrag Formation (Table 6). The Edmonton Formation contains twice as many opaque minerals as the Frenchman and Ravenscrag Formations; also the greater abundance of biotite is a characteristic of the Upper Edmonton Formation (Table 7). The stratigraphic distrib-

ution of the heavy minerals is presented in figures 7 -1 through 7 - 12.

Edmonton Formation

Figures 7 - 1 through 7 - 4 show the regional and stratigraphic distribution of heavy minerals in the Scollard Canyon, Wood Lake, Breda and Trenville sections along the Red Deer Valley.

The Mauve Shale (= Battle Formation) was used as the stratigraphic datum for comparing the four sections. Heavy mineral species in the Upper Edmonton do not show any abrupt change in their distribution. Garnet, the most abundant mineral, attains a maximum of 45.5 percent 50 feet above the Mauve Shale in the Wood Lake section (figure 7 - 2) but otherwise shows a rather uniform distribution in each section. Epidote shows a decrease in the lower 50 feet of the Upper Edmonton and disappears in the basal part in the sections at Trenville and Breda corresponding to the findings of Lerbekmo (1964). Apatite, sphene and chlorite show a fairly uniform distribution. Epidote and zircon are more abundant in the Scollard Canyon section than in more northerly sections, for example, the Trenville section.

Frenchman Formation

The data obtained from the eight sections of the Frenchman Formation, four in Alberta and four in Saskatchewan, are graphed in figures 7 - 5, 6, 7, 8, 9, 10, 11, 12.

The Frenchman Formation is underlain by the Battle, Whitemud or Eastend Formations. The stratigraphic variations of hornblende content within the formation appear to be useful in correlating this unit. The distribution of hornblende in the thick section of this formation along the Elkwater Camp Ground Road was used as the basis

for correlating this formation in other sections. Hornblende is rare or absent in the lower and upper parts of this formation and shows enrichment between 110 and 210 feet above the base of the formation. A low of 2.5 to 10 percent was observed between 60 and 100 feet above the base in the Elkwater Camp Ground Road and Ravenscrag sections, and it is absent in the Eagle Butte and Ravenscrag Butte sections. Hornblende reaches a maximum of 88.5 percent, 190 feet above the base of the formation at the Elkwater Camp Ground Road section.

Epidote has a variable vertical distribution in the Elkwater Camp Ground Road, Old Man on His Back Plateau, and Ravenscrag Butte sections, and in other sections it is fairly uniformly distributed.

Garnet, clinozoisite, sphene and zircon have a uniform regional and stratigraphic distribution in the Frenchman Formation.

Ravenscrag Formation

The Ravenscrag Formation overlying the Frenchman was not originally included in this study. The boundary between the Ravenscrag and Frenchman Formations was placed at the bottom of the Ferris or No. 1 coal seam in the Ravenscrag Butte section by Firnival (1946). The No. 1 coal seam which is well developed along the Frenchman River between Ravenscrag and Eastend decreases in thichness in the western part of the area, for example, along Adams Creek, and is absent in Alberta. Because of the difficulty in placing the boundary between the Frenchman and Ravenscrag Formations in the Adams Creek, Elkwater Highway 48 and Elkwater Scenic Road sections, the heavy mineral study in these sections was carried up into Ravenscrag Formation in an attempt to find additional clues as to the best location for the boundary.

The results of the heavy mineral comparison study of the Ravenscrag Butte

Table 6 Average order of abundance of heavy minerals (excepting biotite) in the Upper Edmonton, Frenchman, and Ravenscrag sandstones.

Upper Edmonton	%	Frenchman	%	Ravenscrag	%
Garnet	28.2	Hornblende	33.5	Epidote	21.3
Apatite	20.1	Epidote	18.4	Garnet	19.1
Zircon	14.7	Garnet	14.2	Tourmaline	13.6
Sphene	9.2	Clinozoisite -Zoisite	8.1	Zircon	12.7
Clinozoisite -Zoisite	6.0	Zircon	7.2	Clinozoisite - Zoisite	12.0
Epidote	5.5	Sphene	6.4	Sphene	6.3
Chlorite	5.4	Apatite	3.7	Rutile	5.6
Rutile	3.8	Tourmaline	1.9	Apatite	5.4
Tourmaline	3.0	Rutile	1.5	Allanite	1.3
Allanite	2.4	Actinolite -Tremolite	1.3	Chlorite	1.1
Andalusite	t	Chlorite	1.0	Andalusite	t
Staurolite	t	Andalusite	t	Actinolite -Tremolite	t
Chloritoid	t	Staurolite	t	Staurolite	t
Brookite	t	Chloritoid	t	Chloritoid	t
Pyroxene	t	Glaucophane	T	Brookite	t
		Pyroxene	t	Pyroxene	t
		Brookite	t		

t less than 1 percent

Table 7 Average percentages of commonest heavy minerals in the Upper Edmonton, Frenchman, and Ravenscrag sandstones.

	Upper Edmonton	Frenchman	Ravenscrag
Hornblende	-	33.5	-
Garnet	28.2	14.2	19.1
Apatite	20.1	3.7	5.4
Zircon	14.7	7.2	12.7
Sphene	9.2	6.4	6.3
Clinozoisite-Zoisite	6.0	8.1	12.0
Epidote	5.5	18.4	21.3
Chlorite	5.4	1.0	1.1
Rutile	3.8	1.5	5.6
Tourmaline	3.0	1.9	1.3
Allanite	2.4	0.9	1.3
Actinolite-Tremolite	-	1.3	0.3
Biotite *	29.5	2.3	6.3
Opaque Minerals +	240.2	106.8	102.7
Average Heavy Minerals Weight %	0.7	1.1	0.4

-: absence

*: Average number of biotite accompanying 100 non-opague minerals.

+: Average number of opaque minerals accompanying 100 non-opague minerals.

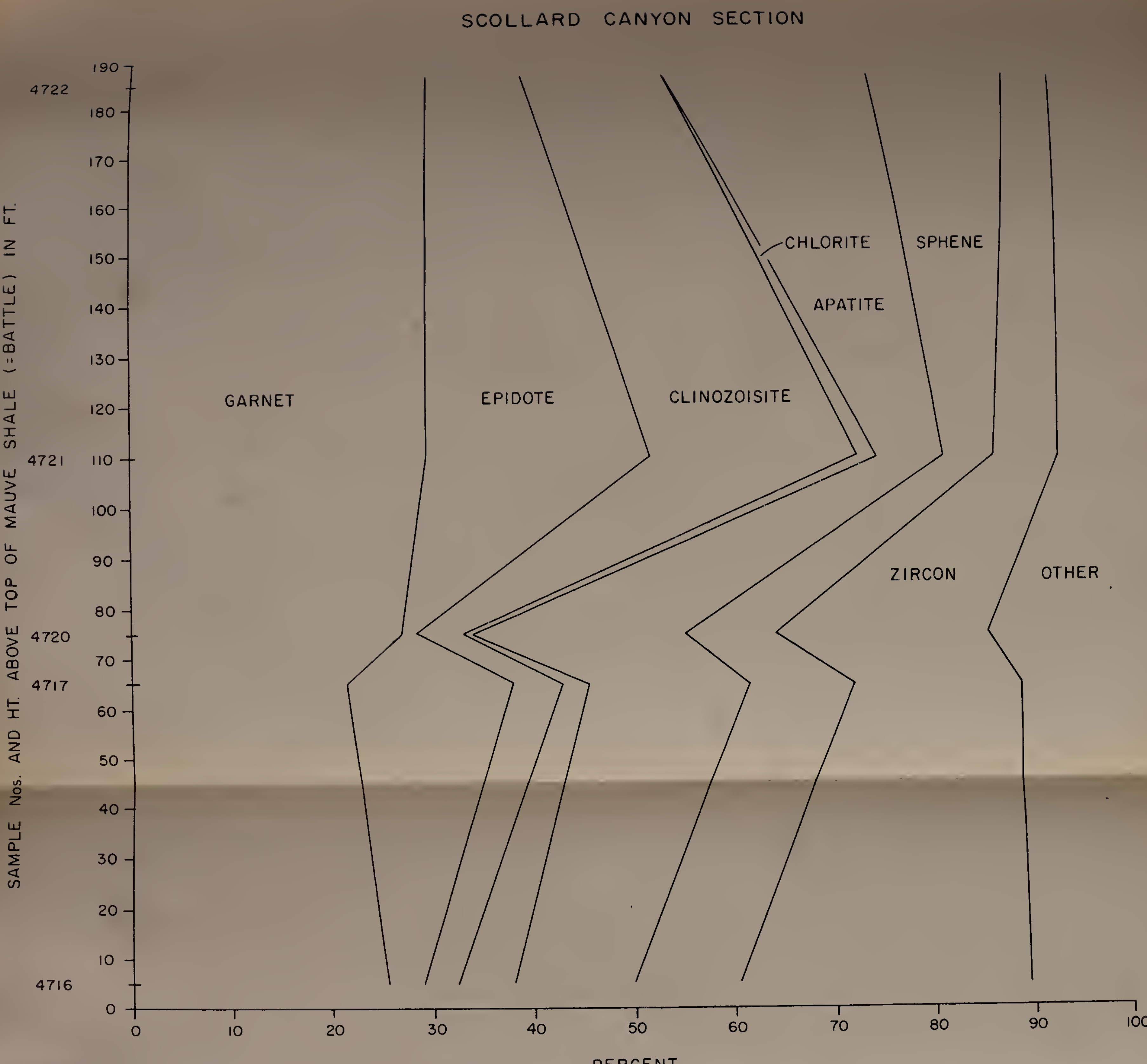

Figure 7-1. Composition and distribution of heavy mineral suites in Upper Edmonton sandstones of the Scollard Canyon section.

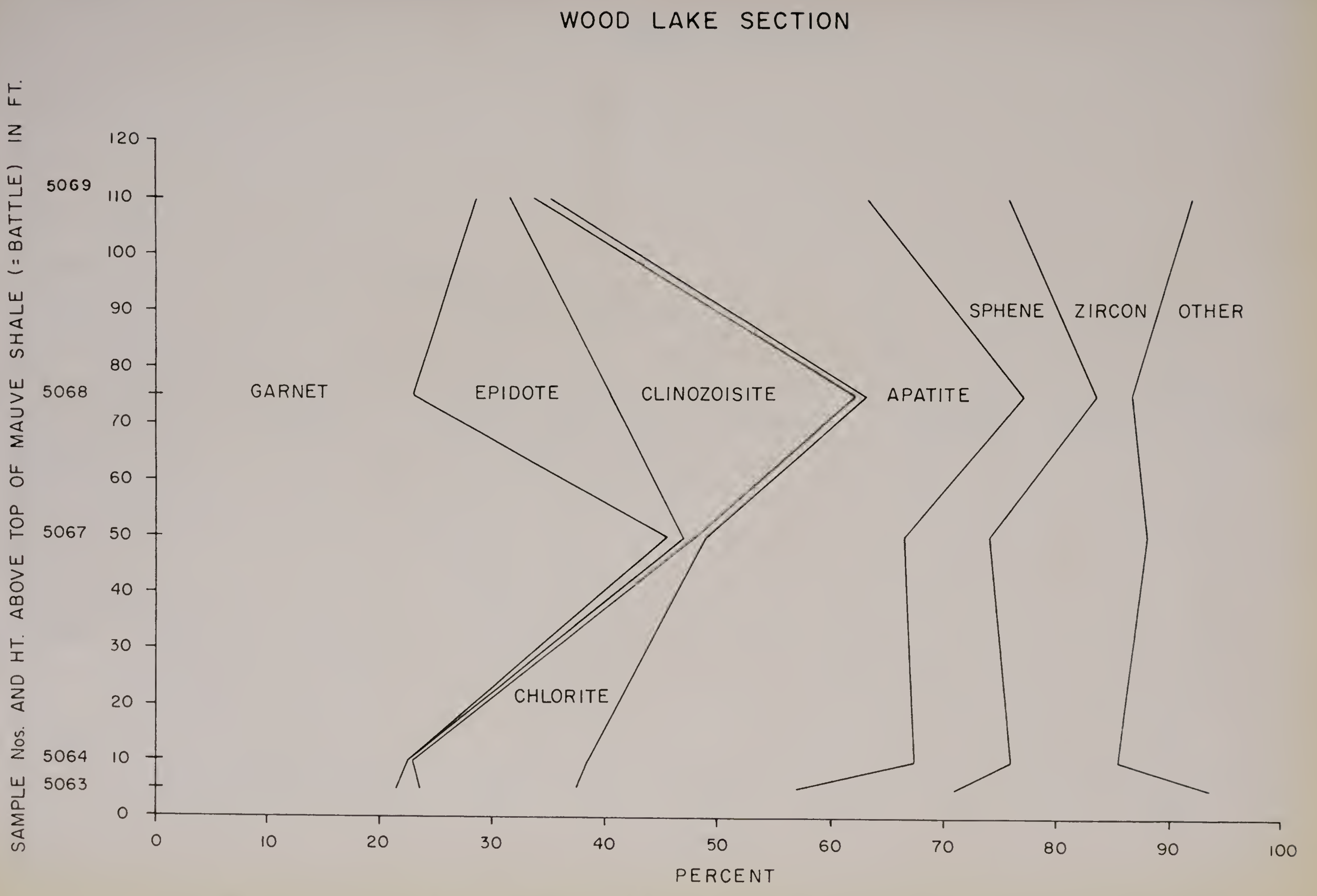

Figure 7-2 Composition and distribution of heavy mineral suites in Upper Edmonton sandstones of the Wood Lake section.

BREDA SECTION

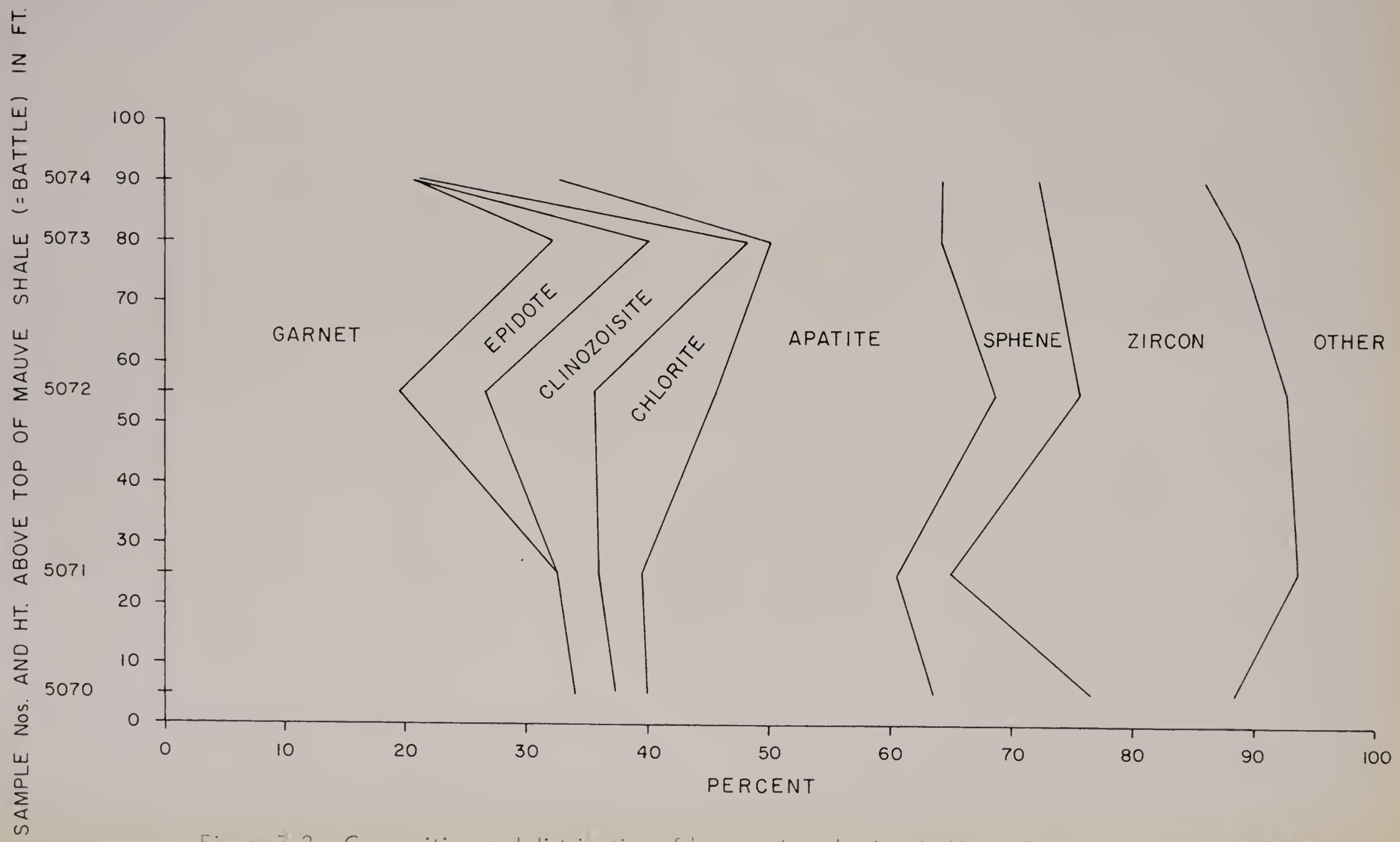

Figure 7-3. Composition and distribution of heavy mineral suites in Upper Edmonton sandstones of the Breda section.

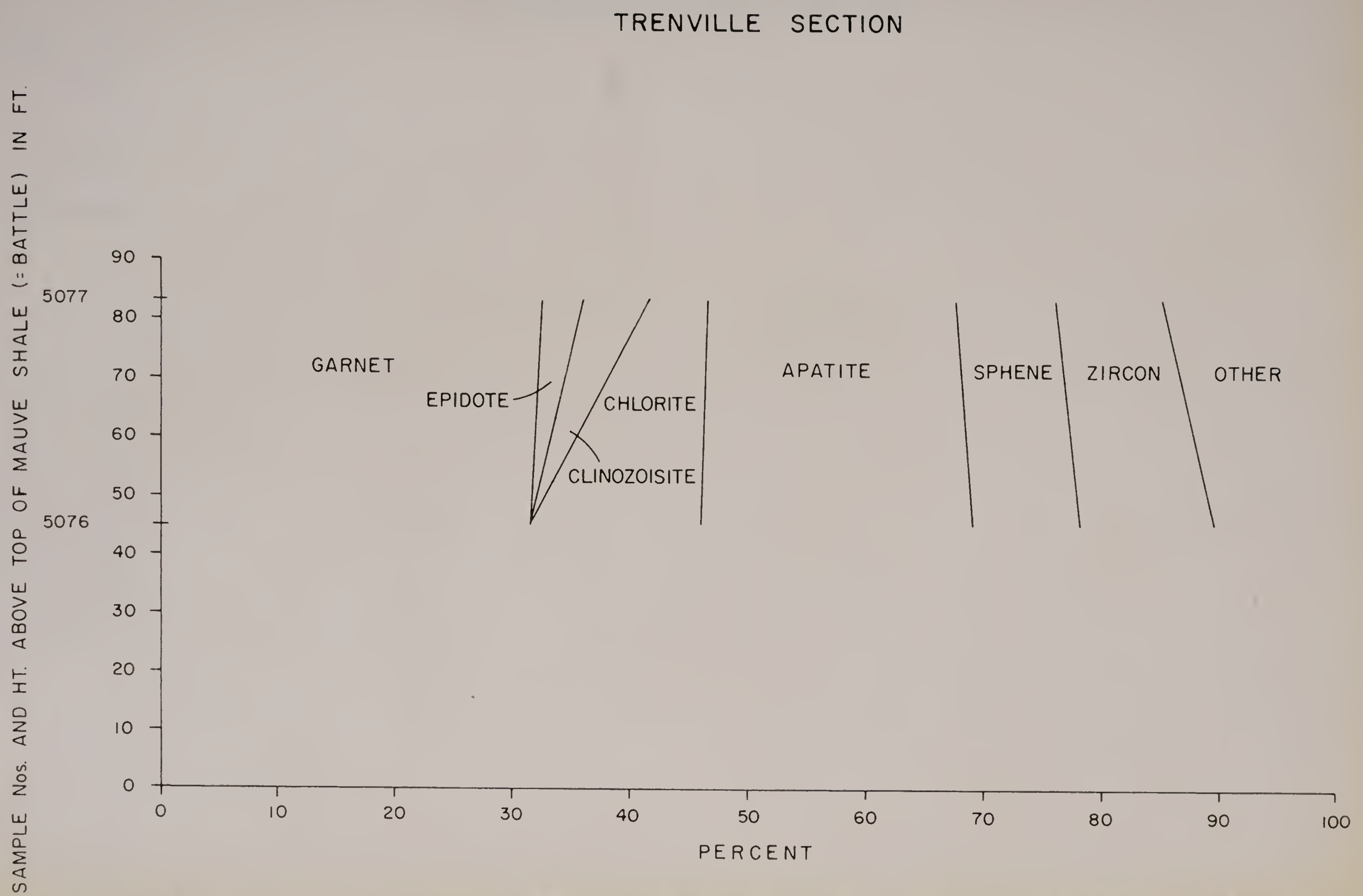

Figure 7-4. Composition and distribution of heavy mineral suites in Upper Edmonton sandstones of the Trenville section.

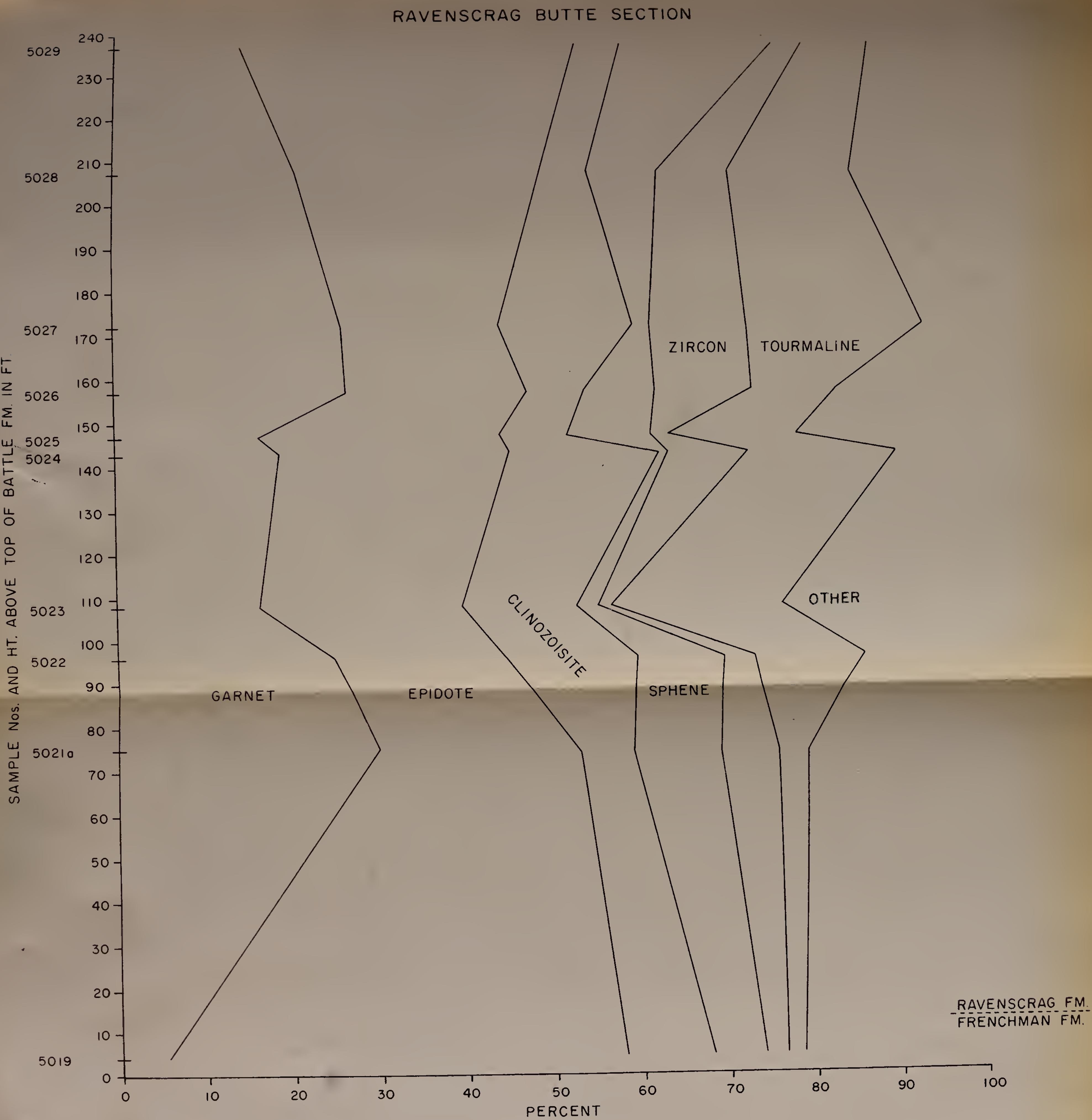

Figure 7-5. Composition and distribution of heavy mineral suites in Frenchman and Ravenscrag sandstones of the Ravenscrag Butte section.

RAVENSCRAG SECTION

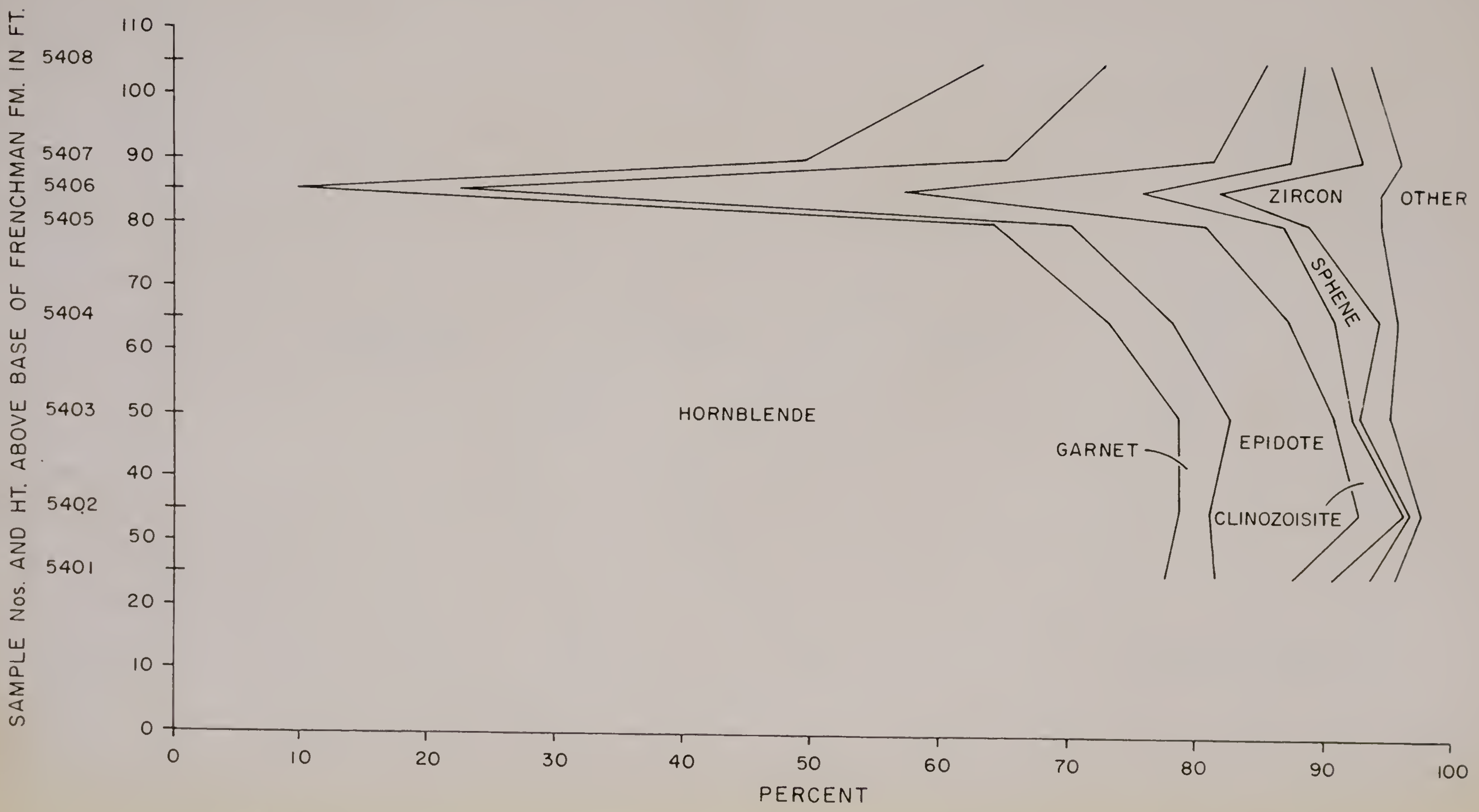

Figure 7-6. Composition and distribution of heavy mineral suites in Frenchman sandstones of the Ravenscrag section.

OLD MAN ON HIS BACK PLATEAU SECTION

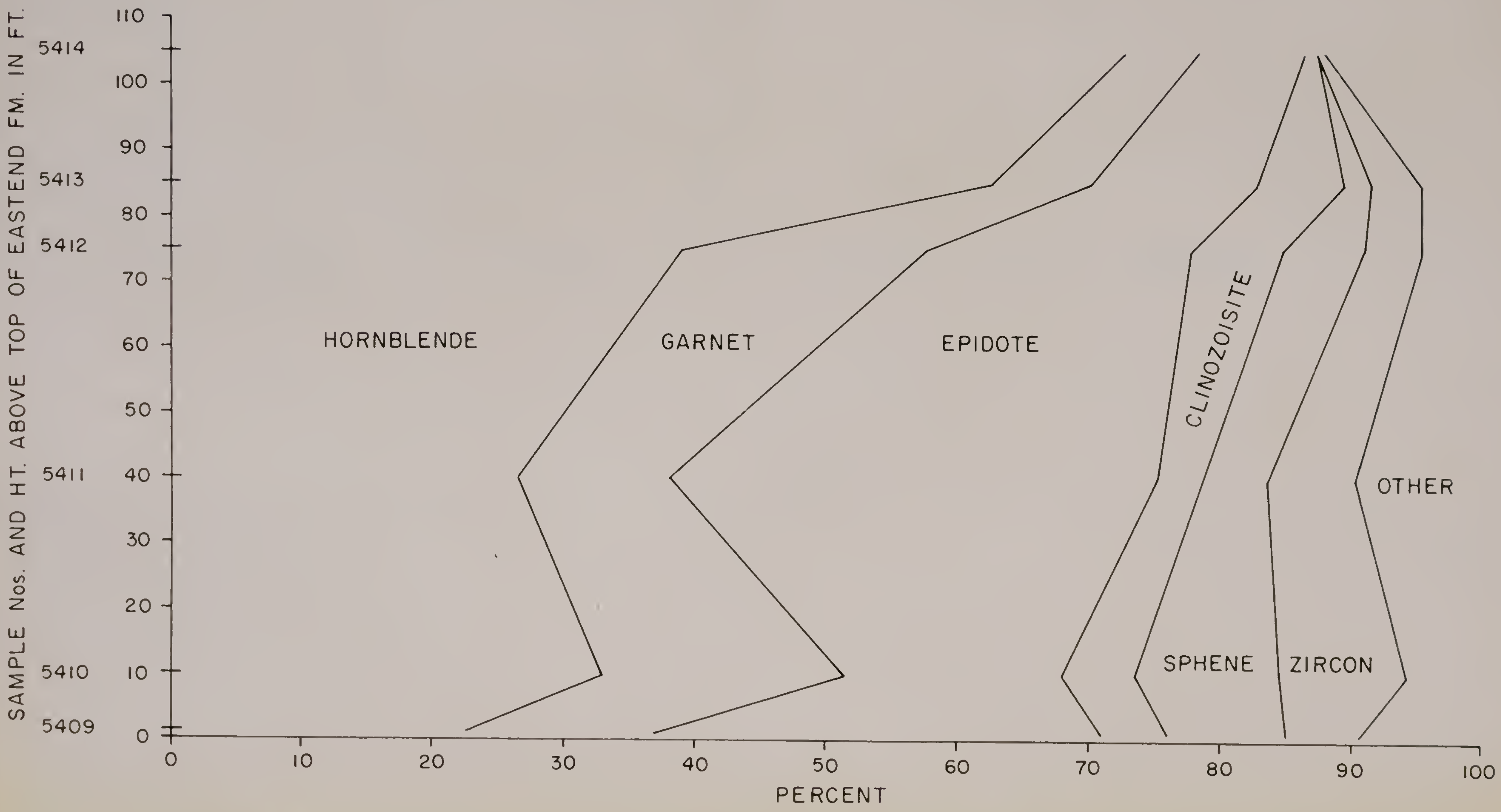

Figure 7-[illegible]. Composition and distribution of heavy mineral suites in Frenchman sandstones of the Old Man On His Back Plateau section.

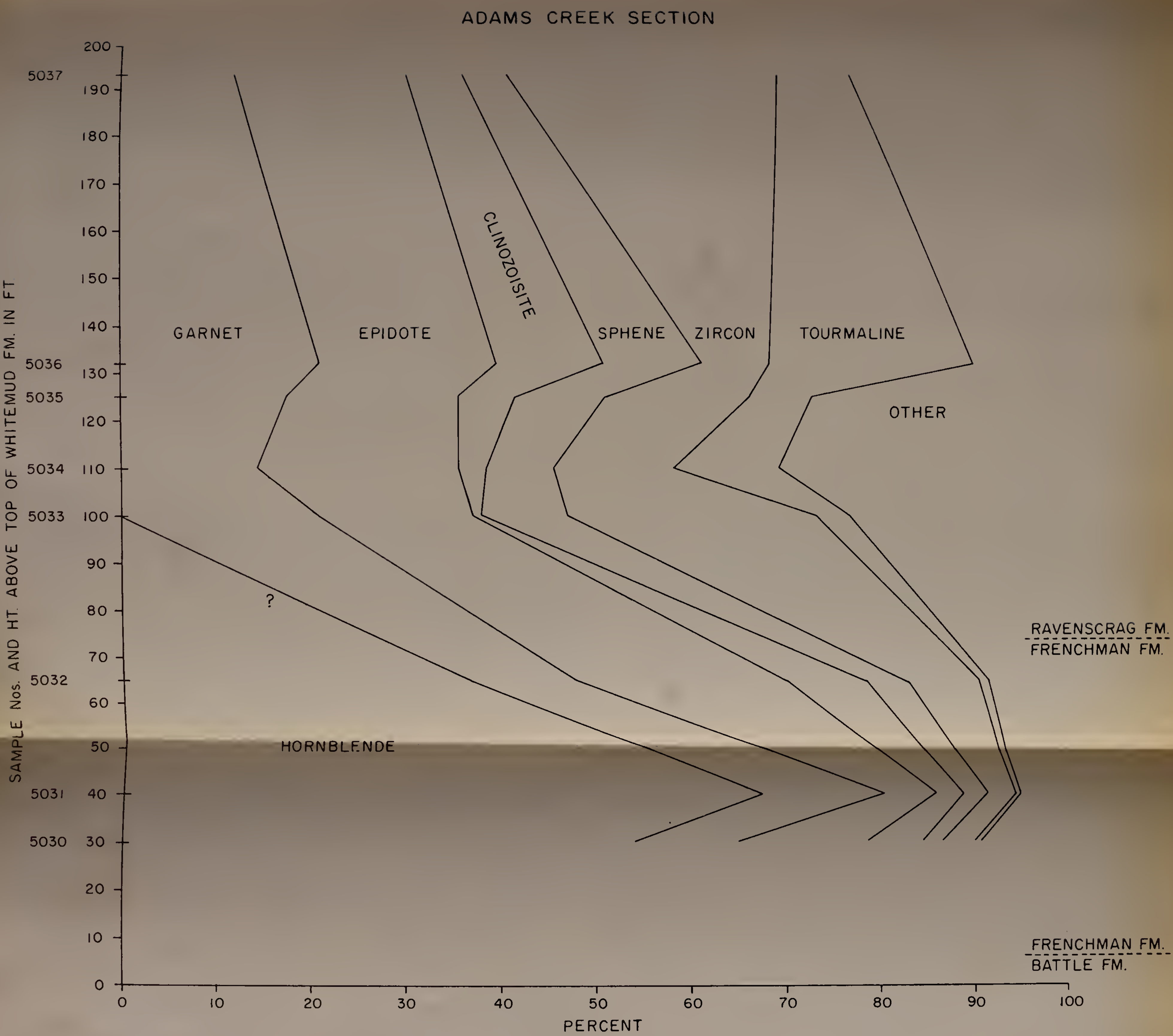

Figure 7-8. Composition and distribution of heavy mineral suites in Frenchman and Ravenscrag sandstones of the Adams Creek section.

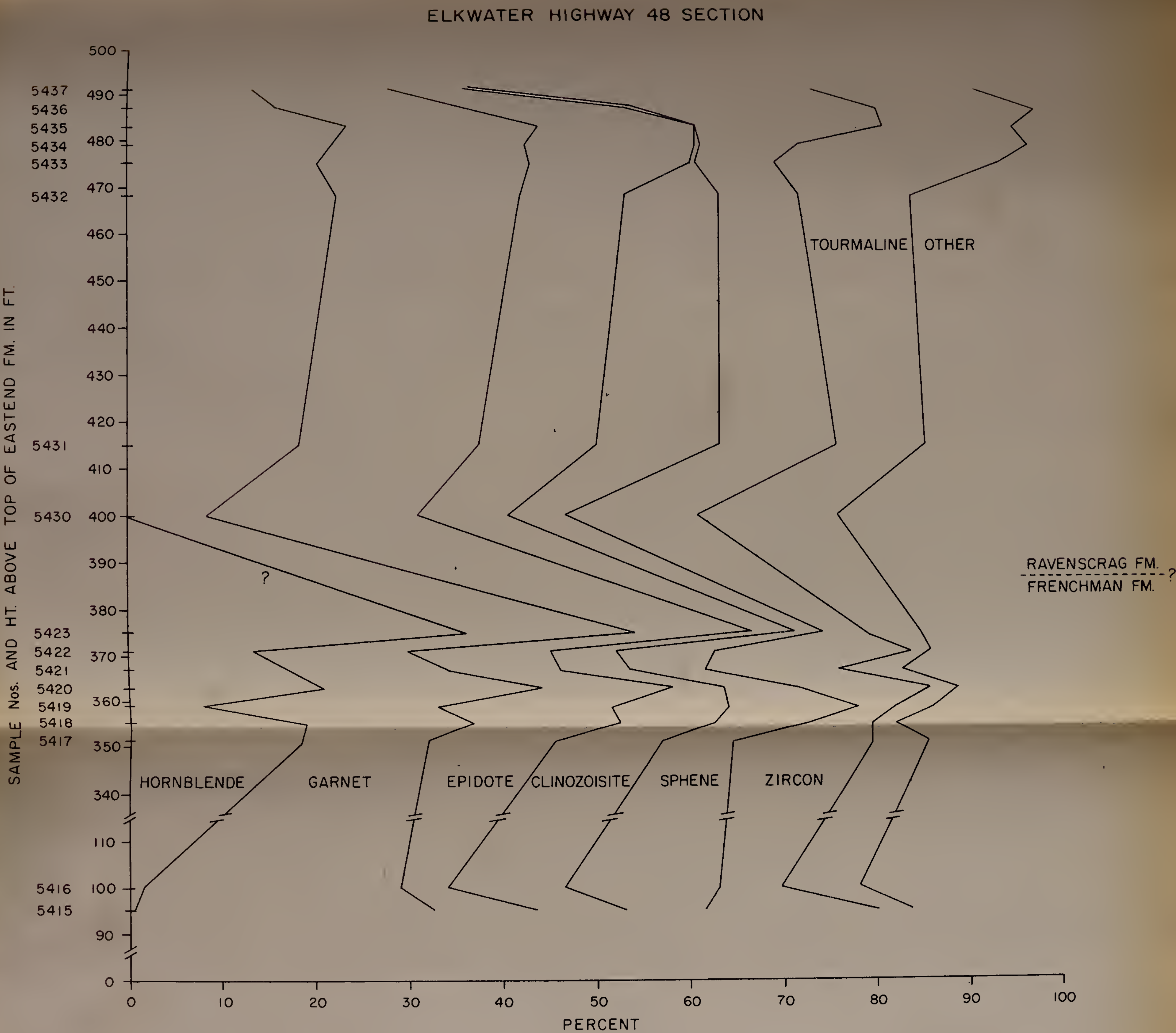

Figure 7-9. Composition and distribution of heavy mineral suites in Frenchman and Ravenscrag sandstones of the Elkwater Highway 48 section.

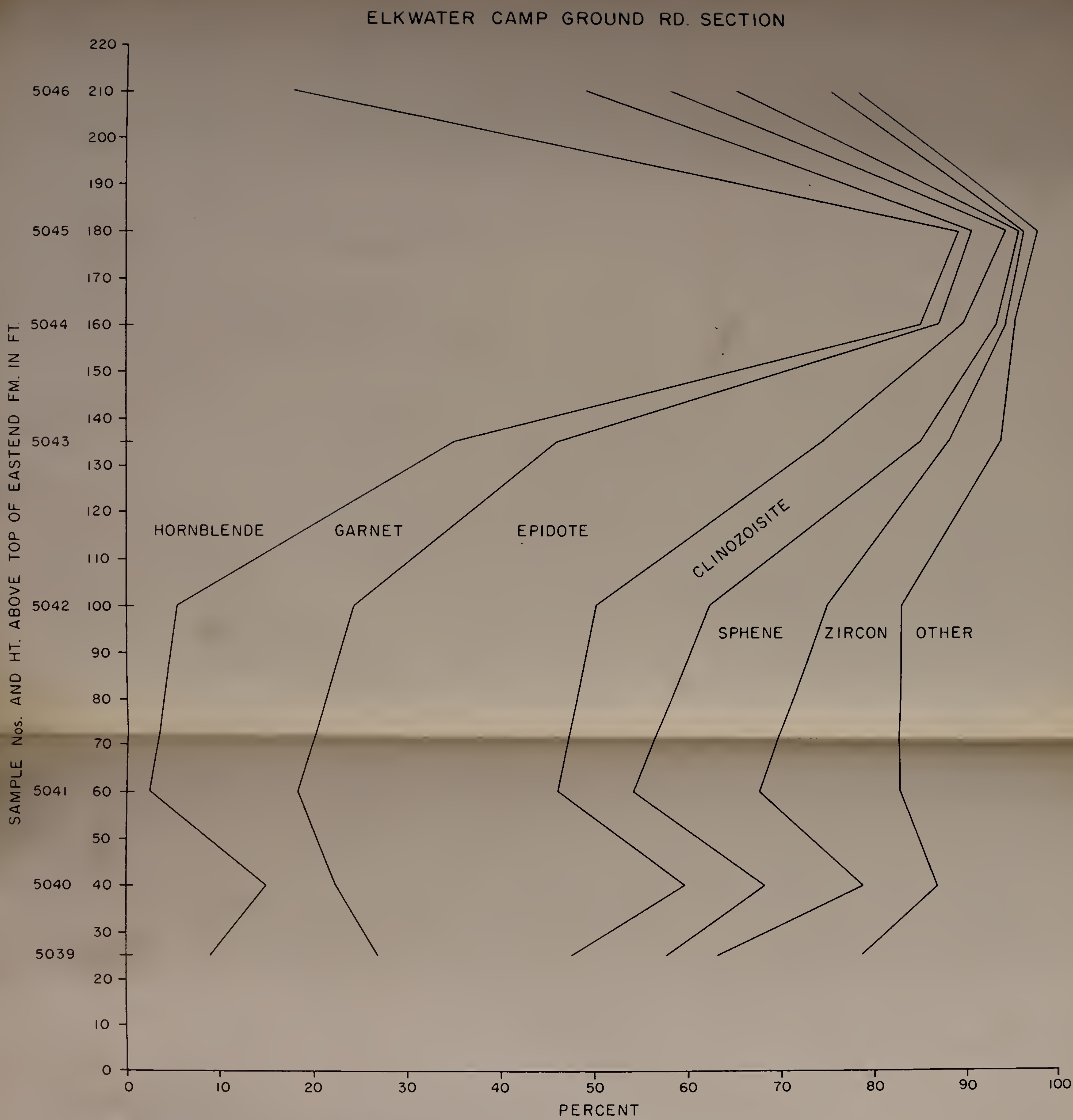

Figure 7-10. Composition and distribution of heavy mineral suites in Frenchman sandstones of the Elkwater Camp ground Rd. section.

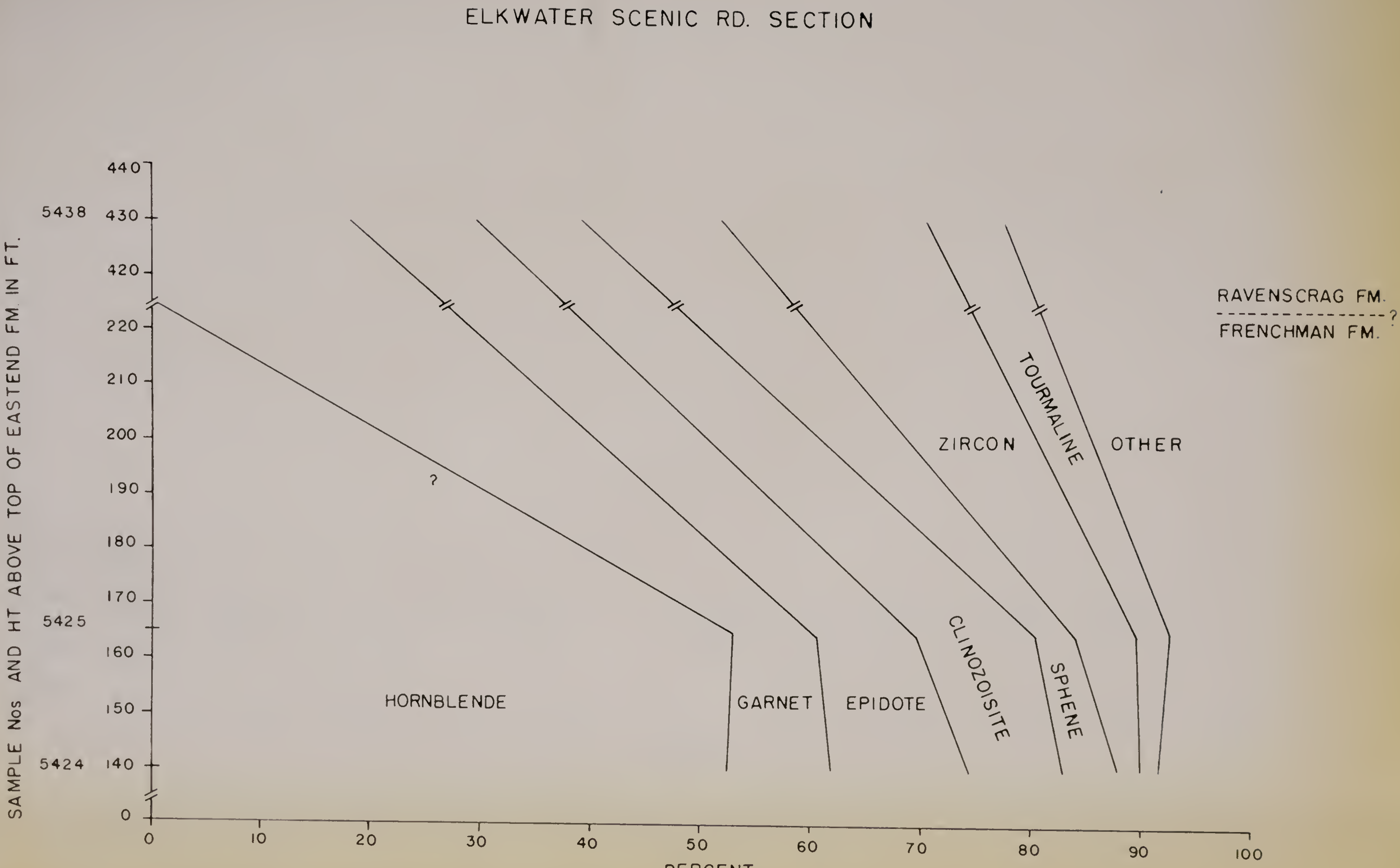

Figure 7-11. Composition and distribution of heavy mineral suites in Frenchman and Ravenscrag sandstones of the Elkwater Scenic Rd. section.

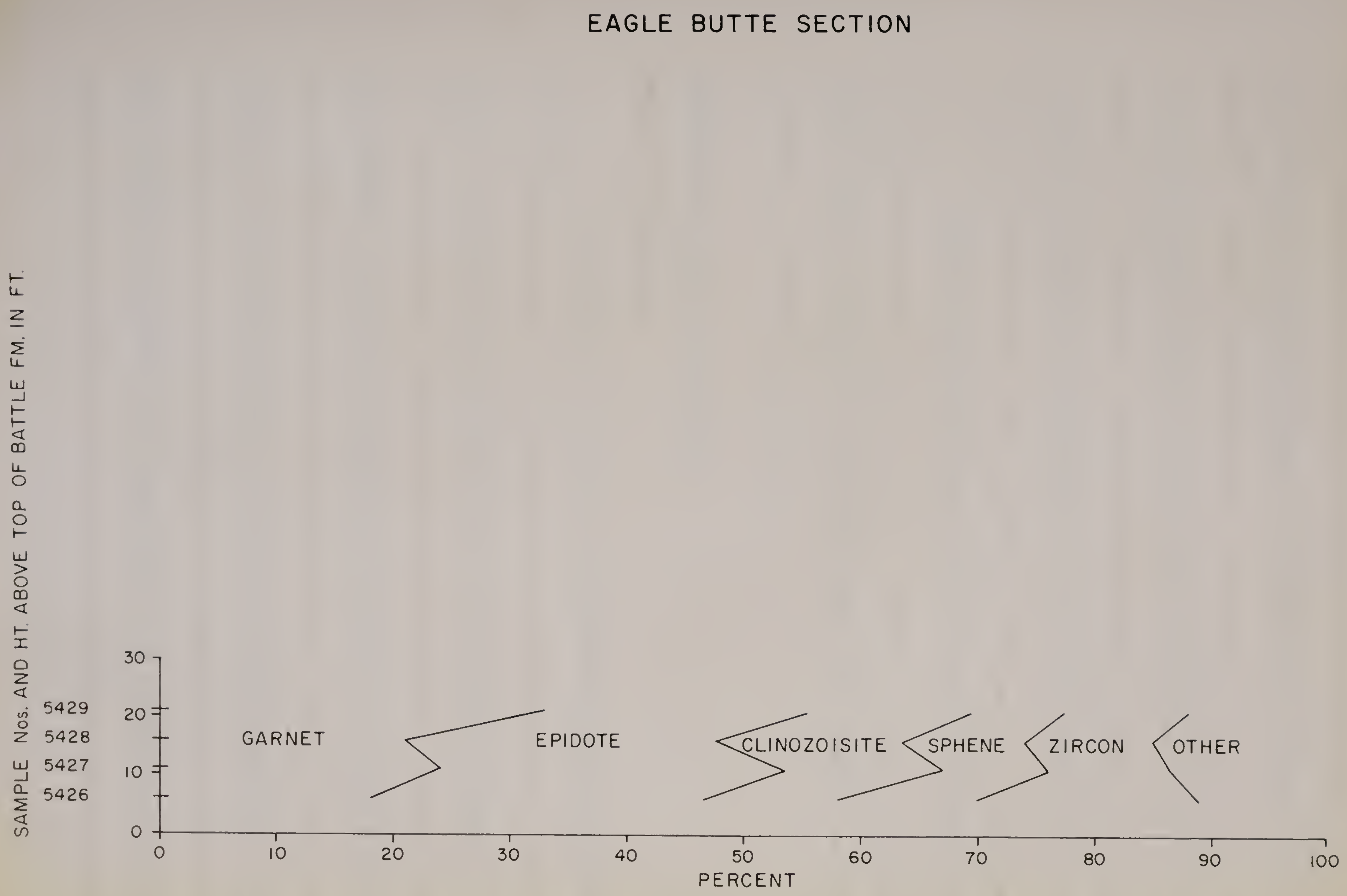

Figure 7-12. Composition and distribution of heavy mineral suites in Frenchman sandstones of the Eagle Butte section.

section with the Adams Creek, Elkwater Highway 48 and Elkwater Scenic Road sections indicates that the Ravenscrag Formation is characterized by a different heavy mineral assemblage than the Frenchman Formation. The Ravenscrag Formation shows an absence of hornblende and an increase in average content of tourmaline to 13 percent (from 1.9 percent in the Frenchman). The absence of hornblende and increase in tourmaline in the above four sections of the Ravenscrag is a useful guide in differentiating it from the Frenchman Formation which contains an average of 33.5 percent of hornblende.

Sphene is rare in the Elkwater Highway 48 section of the Ravenscrag Formation, but is more common and fairly uniform in distribution in the other sections studied. Garnet, epidote, clinozoisite and zircon show rather uniform regional and stratigraphic distributions in the Ravenscrag Formation.

Interpretation of Heavy Mineral Data

Correlation

The abundance of hornblende in the Frenchman Formation and its absence in the Ravenscrag is useful in interpreting the limits of the Frenchman, and may be helpful in tracing the boundary between the Tertiary and Upper Cretaceous in southern Alberta and Saskatchewan in much the same way as was done by Lerbekmo (1964) in central Alberta. The presence of hornblende in an outcrop, a minimum of 375 feet above the base of the Frenchman in the Highway 48 section south of Elkwater Lake, indicates that this outcrop belongs to the Frenchman Formation (see figure 6 - 9). This interpretation means that the thickness of the formation is about 375 to 400 feet which is 125 feet thicker than can be demonstrated in the Camp Ground Road section one mile to the west, described by Russell and Landes (1940) and Crockford (1951).

Furnival (1946) described and measured the Adams Creek section and had some doubt as to whether or not 57 feet of the strata belonged to the Frenchman or the Ravenscrag Formations. The absence of hornblende and an increase of tourmaline in the beds in question indicate that they should belong to the Ravenscrag Formation.

The lack of hornblende in the upper and lower parts of the Frenchman indicates that the thin Eagle Butte and Ravenscrag Butte sections represent only the upper part of the Frenchman Formation. These interpretations are shown in figure 2 which is a modification of the interpretation of Furnival (1946, figure 2).

Significance of Heavy Mineral Stability

Garnet, apatite, hornblende and epidote are abundant heavy minerals in these sandstones, and have long been noted by many authors to be relatively unstable as compared to zircon, rutile and tourmaline (Dryden and Dryden, 1946; Stephen, 1952; and Smith, 1957). The abundance of unstable heavy minerals in these rocks indicates that weathering in the source area did not appreciably deplete the available heavy mineral supply.

The Edmonton and Frenchman sandstones are characterized by an abundance of rock fragments, angular feldspar, and quartz. The compositional maturity of these sandstones based on the ratio of quartz plus chert/feldspar plus rock fragments are classified as immature, according to Pettijohn (1957).

Hubert (1962) has shown that the compositional and textural maturity of sandstones can be correlated with their ZTR Index (total zircon, tourmaline and rutile among the transparent, nonmicaceous, detrital heavy minerals). The abundance of unstable heavy minerals is, therefore, an important criterion of the immaturity of these sandstones. The abundance of angular apatite in the Edmonton Formation and

angular hornblende (not etched) in the Frenchman Formation indicate that mechanical destruction during transportation was not important in modifying the heavy mineral suites in these formations.

Smithson (1941) mentioned that differences in heavy mineral suites in different localities may be caused by :

1. differences in the age of the rocks.
2. alteration or removal of minerals after deposition.
3. the presence of two separate source areas.

Factor 1 is not the reason for the difference in heavy mineral assemblages in the Upper Edmonton and Frenchman Formations because they are approximately of the same age.

Several authors have noted alteration or removal of heavy minerals after depsoition (Brammlette 1941, Pettijohn 1941; Van Andel 1959). The effects of solution have been noticed in hornblende, epidote, tremolite and garnet . The presence of hacksaw terminations on hornblende proves that solution can remove unstable heavy minerals in situ after deposition. However, the occurrences of etched hornblende are limited to 30 feet of strata in the Ravenscrag and Elkwater Camp Ground Road Sections.

It may be concluded from the above discussion that solution has been responsible for the etching grains but has not radically changed the heavy mineral suite in the Frenchman Formation. Also, the co-existence of etched and unetched grains in the Frenchman Formation indicates that the absence of hornblende in the Edmonton Formation cannot be readily explained simply by intratratal solution. Therefore, it is concluded that the differences in the heavy mineral assemblages from the Edmonton and Frenchman Formations can best be explained by two separate source areas.

The relative stability of the observed unstable heavy minerals in intrastratal solutions has been examined by comparing etched minerals present in the samples studied. It was found that :

1. Apatite is uncorroded where the accompanying hornblende, epidote and garnet are etched.
2. Etched epidote is common but only a few garnet grains are corroded.
3. Hornblende grains show strongly etched terminations whereas accompanying epidote and garnet are uncorreded.
4. Tremolite has fewer etched terminations than hornblende but is more corroded than epidote.

The above observations indicates the following order of stability (listed in order of decreasing stability).

Apatite
Garnet
Epidote
Tremolite
Hornblende

CHAPTER SIX

SUMMARY AND CONCLUSIONS

The composition of the sandstones of the Frenchman and Upper Edmonton Formations can be summarized as follows :

	Frenchman Formation	Upper Edmonton Formation
Colour	Dusky yellow to yellowish gray	Grayish white to pale yellowish gray
Grain size	Medium to fine grained	Medium to fine grained
Sorting	Moderate	Poor
Textural maturity	Submature	Submature to immature
Feldspars	Na-feldspar more common than K-feldspar	K-feldspar more common than Na-feldspar
Rock fragments	21 to 43 %	21 to 53 %
Carbonates	Calcite concretionary cementation common	Calcite cement common (non-concretionary)
Mica	Rare	Common to abundant (roughly 10 times as much as in Frenchman)
Characteristic non-opaque heavy minerals	Hornblende (av. 33.5%) Epidote (av. 18.4%) Garnet (av. 14.2%)	Garnet (av. 28.2%) Apatite (av. 20.1%) Zircon (av. 14.7%)
Opaque heavy minerals	Common	Abundant (approximately twice as much as in Frenchman)
Average total content of heavy minerals	1.1%	0.7%
Induration	Poorly to highly indurated	Moderately indurated
Classification	Mostly lithic sandstones (7 of 9 samples)	Mostly rock fragment sandstone (6 of 12 samples)

Depositional Environment

The statistical size parameters of the Frenchman and Upper Edmonton sandstones indicate that they were probably deposited under similar conditions. They are characterized by fine to medium grain size, and lack of effective sorting within the finer sizes. Clastic grains greater than 1 mm in diameter did not arrive at the site of deposition. The presence of fresh angular feldspar, apatite and hornblende indicate that there was little time for weathering in either the source area or at the site of deposition. These features suggest that the depositing agent had moderately low energy, but that the source area relief was fairly high, and erosion and deposition of the sediment were rapid.

The similarity of the size parameters of the Frenchman and Upper Edmonton sandstones to stream sands studied by Folk and Ward (1957) and Friedman (1961) indicates that sandstones of these two formations were largely formed in a fluvial environment. The lenticular shape and crossbedding in the sandstones also tend to verify the above conclusions, as do the presence of roots, stems and similar carbonaceous material.

Provenance

The composition of a sediment is controlled by source rocks, climate and relief within the source region. It was concluded that the major differences in composition between the Frenchman and Edmonton Formations may best be explained by different provenances.

Upper Edmonton

The study of heavy minerals and thin sections indicate that the most of the clastic materials of this formation were derived from types of terrane which are believed to have existed to the west of this formation. The abundance of sedimentary

rock fragments (chert, mudrock and siltstone) in addition to quartz indicate that sedimentary rocks (carbonates, shales and sandstones) were the major source of this unit. The presence of much well rounded zircon and rounded tourmaline support this conclusion. Most of the well rounded zircons are purple varieties which are indicative of Precambrian or early Paleozoic age. The presence of hyacinth grains in the Creston quartzite and the Purcell diorite sills of late Precambrian age in the Kimberley area of southern British Columbia has been mentioned by Beveridge (1956) and are examples of possible source rocks.

The abundance of garnet, and the presence of clinozoisite, zoisite, epidote, chlorite, andalusite and staurolite indicate derivation from a metamorphic terrane of varying grade. Also, the low grade metamorphic rock fragments, argillite and metasiltstone are indicative of primary metamorphic sources. Possible source rocks of these types are widespread in southeastern British Columbia.

The presence of apatite, euhedral zircon, sphene and pink tourmaline indicate acid igneous sources. The excess of orthoclase over plagioclase and the abundance of biotite also suggest acidic igneous rocks. Volcanic rock fragments and some of the euhedral zircon show some volcanic contribution.

It is concluded that the detrital grains of this formation are derived mainly from a sedimentary source with lesser contribution from metamorphic and acid igneous rocks. The present study supports the conclusion of Allan and Sanderson (1945) that the source areas of this formation were near the region now occupied by the Selkirk Mountains and the Interior Plateau of British Columbia, but precise areas or source rocks cannot yet be designated.

Frenchman

The abundance of sedimentary rock fragments in the Frenchman Formation shows that this formation too was derived mainly from sedimentary rocks. The abundance of hornblende and the higher percentage of plagioclase than orthoclase suggest that basic igneous rocks were more prominent in the source area of this formation than in that of the Edmonton.

The importance of coloured apatite for tracing the source areas has been discussed by several authors (Fleet and Smithson, 1928; Groves, 1927 and Simpson, 1933). Apatite separated by Dr. H. Baadsgaard from 21 samples of Precambrian rocks in the northeastern corner of Alberta collected by Dr. J. D. Godfrey (1963) were examined with the hope of finding brown apatite. Granite A from N.E. Andrew Lake Map Sheet and Granite C from Waugh Lake Map Sheet have brown apatite which appears identical to that found in the Frenchman Formation. The rareness and apparent limitation of its occurrence to certain types of igneous rock provides a possible tool for evaluating limited source areas. The different types of reddish brown apatite in this formation suggests that several provinces of igneous rocks may have contributed to these rocks, including possibly the northeast Alberta area.

Most of the rounded hyacinth varieties of zircon were derived from pre-existing sedimentary sources, but minor amounts are possibly of first cycle derivation, perhaps from the Canadian Shield. Some of the euhedral colourless zircons and the volcanic rock fragments indicate that a volcanic source was also present. Epidote, garnet, clinozoisite, zoisite, andalusite, staurolite, chlorite, chloritoid and low grade metamorphic rock fragments are indicative of a varied metamorphic source.

Thus, the Frenchman Formation, like the Edmonton, is derived from

sedimentary rocks as a major source with lesser contributions from igneous and metamorphic rocks, but at least some of the igneous sources were not the same for the two formations. Differentiation between these source areas may be aided by studies of directional properties in the two formations followed by compositional studies of suggested source terrains. Scanty evidence available suggests a shield contribution to the Frenchman Formation. Such a source would be easier to envisage if the Frenchman were somewhat younger than the Upper Edmonton, a possibility not yet disproved.

Finally, the stratigraphic variation of hornblende frequencies in the Frenchman may be used in correlating stratigraphic units within the formation, and the absence of hornblende and increase in tourmaline in the Ravenscrag Formation are useful criteria for differentiating this formation from the Frenchman at approximately the Tertiary-Cretaceous boundary. This discovery proves the further problem of the relationship between hornblende bearing Paskapoo sandstone of the Red Deer Valley described by Lerbekmo (1964) and the supposedly equivalent Ravenscrag Formation.

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APPENDIX A

Location of the samples

UPPER EDMONTON MEMBER

Section	Sample	Position
Scollard Canyon (NE. 1/4, sec. 18, tp. 34, rge. 21)	4722	5' above upper Ardley seam (185' above top of Mauve shale)
	4721	110' above top of Mauve shale
	4720	75' " "
	4717	65' " "
	4716	5' " "
Wood Lake (E. 1/2, sec. 14, tp. 37, rge. 22)	5069	5' above Ardley seam (110' above top of Mauve shale)
	5068	75' above top of Mauve shale
	5068a	75' " "
	5067	50' " "
	5065	18' " "
	5064	10' " "
	5063	5' " "
Breda (NE. 1/4, sec. 12, tp. 36, rge. 22)	5074	90' above top of Mauve shale
	5073	80' " "
	5072	55' " "
	5071	25' " "
	5070	5' " "
Trenville (E. 1/2, sec. 24, tp. 36, rge. 22)	5077	83' above top of Mauve shale
	5076	45' " "
Bio Valley (NW. 1/4, sec. 33, tp. 35, rge. 21)	4709	60' above Kneehills Tuff bed
	4711	35' " "

Frenchman Formation

Section	Sample	Position
Ravenscrag Butte (W. 1/2, sec. 26, tp. 6, rge. 23)	5019	4' above top of Battle Formation
One and half miles north-west of Ravenscrag (NE. 1/4 sec. 26, tp. 6, rge. 24)	5408	105' above base of Frenchman Formation
	5407	90' " "
	5406	85' " "
	5405	80' " "
	5404	65' " "
	5403	50' " "
	5402	35' " "
	5401	25' " "
Old Man On His Back Plateau (NE. 1/4 sec. 34, tp. 2, rge. 25)	5414	105' above top of Eastend Formation
	5413	85' " "
	5412	75' " "
	5411	40' " "
	5410	10' " "
	5409	1' " "
Adams Creek (SE. 1/4 sec. 17, tp. 7, rge. 28)	5032	65' above top of Whitemud Formation
	5031	40' " "
	5030	30' " "
Elkwater, along Highway 48 (secs. 18, and 19, tp. 8, rge. 2)	5423	375' above top of Eastend Formation
	5422	371' " "
	5421	367' " "
	5420	363' " "
	5419	359' " "

Section	Sample	Position
Elkwater, along Highway 48 (secs. 18, and 19, tp. 8, rge. 2)	5418	355' above top of Eastend Formation
	5417	351' " "
	5416	100' " "
	5415	95' " "
Elkwater, camp ground (secs. 13, 14, and 24, tp. 8, rge. 3)	5046	210' above base of Frenchman Formation
	5045	180' " "
	5044	160' " "
	5043	135' " "
	5042	100' " "
	5041	60' " "
	5040	40' " "
	5039	25' " "
Elkwater, Scenic road (secs. 14, and 23, tp.8, rge. 3)	5425	165' above top of Eastend Formation
	5424	140' " "
Eagle Butte (sec. 9, tp. 8, rge. 4)	5429	21' above top of Battle Formation
	5428	16' " "
	5427	11' " "
	5426	6' " "

Ravenscrag Formation

Section	Sample	Position
Ravenscrag Butte (W. 1/2, sec. 26, tp. 6, rge. 23)	5029	237' above top of Battle Formation
	5028	207' " "
	5027	172' " "
	5026	157' " "
	5025	147' " "
	5024	143' " "
	5023	108' " "
	5022	96' " "
	5021a	75' " "
	5021	75' " "
Adams Creek (SE. 1/4, sec. 17, tp. 7, rge. 28)	5037	193' above top of Whitemud Formation
	5036	132' " "
	5035	125' " "
	5034	110' " "
	5033	100' " "
Elkwater, along Highway 48 (Secs. 18, and 19, tp. 8 rge. 2)	5437	491' above top of Eastend Formation
	5436	487' " "
	5435	483' " "
	5434	479' " "
	5433	475' " "
	5432	468' " "
	5431	415' " "
	5430	400' " "
Elkwater, scenic road (secs. 14, and 23, tp. 8, rge. 3)	5438	430' above top of Eastend Formation

APPENDIX B

Procedure of Mechanical analysis

Disaggregation

The samples used for size analysis were classified by adding a drop of dilute hydrochlolic acid and observing the reaction under a binocular microscope in order to decide the best method of disaggregation. All samples belong to one of the following categories.

1. Unconsolidated sediments free from carbonate and ferruginous cements.
2. Unconsolidated sediments with minor amounts of carbonate cement.
3. Consolidated sediments with a carbonate cement.
4. Unconsolidated sediments with ferruginous cement.

All samples belonging to category l were placed on a large piece of plate glass and then crushed with the fingers. After crushing the sample with fingers to less than pea size, the aggregates were crushed further using a wooden roller. Because of the difficulty in crushing a small amount of aggregate material mixed with disaggregate material, the two fractions were separated by screening and the aggregates were then subjected to further crushing. The samples were examined under the binocular microscope to ensure thorough disaggregation.

The samples belonging to categories 2 and 3 were placed in dilute hydrochloric acid (20% HCl) until the carbonate cement was removed. Before adding the acid to consolidated samples, they were crushed using a jaw crusher. The clay content in the sample after acid treatment was separated by decantation on to a filter paper, which was placed in an oven to dry. Later the clay weight was added to the pan fraction of the sieve analysis. The sand sample was also washed and dried.

The samples belonging to category 4 were placed in 50% HCl with $SnCl_2$

and boiled over a lamp until all ferruginous coating of the grains was removed. The following steps were the same as in calcite cement.

Sieving

Using a Jones sample splitter, about 100 grams of disaggregated sample was obtained. This sample was passed through a series of eight-inch diameter screens of U.S. standard mesh nos. 35, 45, 60, 80, 120, 140, 170 and 230. The sample was sieved for two 10-minute in a Tyler Ro-Tap because this machine could not load all the screens at one time. All fractions of the sample contained on each mesh were weighed to 0.01 gram. The pan fraction was saved for pipette analysis.

Pipette Analysis

Fine-grained sediment smaller than 1/16 mm can be separated into silts and clays by various methods ; elutriation, decantation, hydrometer and pipette. Most methods are based on the settling velocity of the partivles in the liquids, computed on the basis of Stockes' formula. From the comparison of the accuracy between the hydrometer and the pipette methods, Sternberg and Creager (1961) concluded that the pipette method gave fair results with the silt and clay concentration of less than 6 g/l. With concentration greater than 24 g/l, the hydrometer analysis was more efficient. Within a moderate range of silt and clay concentration (6 to 24 g/l), the analysis gave similar results for the 5 Ø through 9 Ø size grades.

Because of the simplicity of the required apparatus and accuracy, the pipette method was used to analyze silts and clays. The pipette method was developed by Robinson (1922) and Jennings, Thomas, and Gardner (1922) and well described by Krumbein and Pettijohn (1938), Twenhofel and Tyler (1941), and Folk (1961).

A 0.1 percent solution of Sodium hexametaphosphate (Calgon, $Na_3(PO_4)_6$) was used as a dispersant and time of withdrawal for clay size was calculated at room temperature 28°C to be 1 hour and 42 minutes by Folk's formula (1961). The procedure described by Folk (1961, p. 36) was used in this study.

Formulae for statistical parameters

The following formulae used to calculate the statistical parameters are taken from Inman (1952) and Folk (1961).

Median

Median diameter is the value corresponding to the 50 percent line on the cumulative curve. This diameter is larger than 50 percent of the particles by the weight and smaller than 50 percent.

Graphic Mean (M_Z) (Folk)

The graphic mean is a measure of average.

$$M_Z = \frac{\emptyset 16 + \emptyset 50 + \emptyset 84}{3}$$

Graphic Mean (Inman)

$$\text{Mean} = \frac{\emptyset 16 + \emptyset 84}{2}$$

Graphic standard deviation (σ_G) (Inman)

The graphic standard deviation is a measure of dispersion.

$$\sigma_G = \frac{\emptyset 84 - \emptyset 16}{2}$$

Inclusive graphic standard deviation (σ_I) (Folk)

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

The following verbal limits are suggested by Folk

under 0.35 ϕ	very well sorted
0.35 ϕ - 0.50 ϕ	well sorted
0.50 ϕ - 0.71 ϕ	moderately well sorted
0.71 ϕ - 1.0 ϕ	moderately sorted
1.0 ϕ - 2.0 ϕ	poorly sorted
2.0 ϕ - 4.0 ϕ	very poorly sorted
over 4.0 ϕ	extremely poorly sorted

Graphic skewness (SK_G) (Inman)

Graphic skewness is a measure of asymmetry.

$$SK_G = \frac{\phi 16 + \phi 84 - 2\phi 50}{(\phi 84 - \phi 16)}$$

Inclusive graphic skewness (SK_I)(Folk)

$$SK_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

The following verbal limits are suggested by Folk.

SK_I from + 1.00 to + 0.30,	strongly fine skewed
+ 0.30 to + o.10,	fine skewed
+ 0.10 to - 0.10,	near symmetrical
- 0.10 to - 0.30,	coarse skewed
- 0.30 to - 1.00,	strongly coarse skewed

Graphic kurtosis (K_G) (Folk)

Graphic kurtosis is a measure of peakedness.

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

If the curve is more peaked than the normal distribution, it is called leptokurtic ; if less peaked, platykurtic. The following verbal limits are suggested by Folk.

K_G under 0.67	very platykurtic
0.67 - 0.90,	platykurtic
0.90 - 1.11,	mesokurtic
1.11 - 1.50,	leptokurtic
1.50 - 3.00,	very leptokurtic
over 3.00	extremely leptokurtic

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

APPENDIX C

Heavy Mineral Data

TABLE A-1

PERCENTAGES OF HEAVY MINERALS IN SCOLLARD CANYON SECTION (UPPER EDMONTON)

Sample No.		4716	4717	4720	4721	4722
Hornblende	(brown					
	(green					
Garnet	(colourless	18	16.5	17	24	25.5
	(pink	7.5	5	10	5.5	4
Epidote		3.5	16.5	1.5	22	9.5
Clinozoisite		3.5	5	4.5	20.5	14
Zoisite						
Apatite	(colourless	11	15.5	18.5	6.5	17.5
	(coloured	1	T	2.5		3
Andalusite		1	1.5	0.5	1.5	1
Rutile	(red				T	
	(yellow	4.5	5.5	4	1.5	5
Sphene		10.5	10.5	9	5	13.5
Tourmaline	(blue					
	(brown	T	1	4	1	
	(green		1	T	1	
	(pink			1.5		T
	(yellow	T	1	1		T
	(colourless					
Actinolite						
Allanite		3.5	T	3	2	1.5
Chlorite		5.5	2.5	1	2	
Zircon	(Euhedral			T*	T*	
	(Euhedral	7.5	2	7	4.5	1.5
	(Subhedral	T*	T*			
	(Subhedral	3	T	6	1	
	(Well round	5.5*	1*			1*
	(Well round	5.5	6.5	4.5		1
	(Anhedral		2.5*			
	(Anhedral	7	3.5	3	T	1
Staurolite				T	T	
Chloritoid						
Brookite			T			
Pyroxene			T			
Biotite	(red	8	8	1		
	(brown	10	14	5	5	1
Opaque	(red	6	24	193	7	5
	(black	251	258	139	120	104

*: Hyacinth
T: Less than 1%
Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-2

PERCENTAGES OF HEAVY MINERALS IN WOOD LAKE SECTION (UPPER EDMONTON)

Sample No.		5063	5064	5067**	5068	5069
Hornblende	(brown					
	(green					
Garnet	(colourless	14	17	30	14	22
	(pink	7.5	5.5	25.5	9	6.5
Epidote				1.5	17.5	3
Clinozoisite		2	T	1	21.5	2
Zoisite						
Apatite	(colourless	14	25.5		12.5	25
	(coloured	5.5	3.5		1.5	3
Andalusite			1	T	1	
Rutile	(red	T		T	T	
	(yellow	3	5	1	6.5	4.5
Sphene		14	8.5	9.5	6.5	12.5
Tourmaline	(blue					
	(brown	T	T	4.5		
	(green	2	1	3.5	T	
	(pink			1	T	
	(yellow	1	1.5			T
	(colourless	T		T		
Actinolite						
Allanite		2.5	5	1.5	1.5	3
Chlorite		14	15.5	1	1	1.5
Zircon	(Euhedral		T*			T*
	(Euhedral	7.5	2.5	4		4.5
	(Subhedral		T*	T*		
	(Subhedral	4		2.5		2
	(Well round	2*	2*	1.5*	T*	T*
	(Well round	4.5	1	4.5	1.5	2
	(Anhedral			1.5*		
	(Anhedral	T	3	25	1	6.5
Staurolite		T	T		2	T
Chloritoid						
Brookite						
Pyroxene				1.5		
Biotite	(red		1		3	6
	(brown	6	19	1	16	22
Opaque	(red	52	187	18	5	6
	(black	156	98	177	163	196

* Hyacinth

** Treated with HCl

T less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-3

PERCENTAGES OF HEAVY MINERALS IN BREDA AND TRENVILE SECTIONS (UPPER EDMONTON)

		Breda					Trenville	
Sample No.		5070	5071	5072	5073	5074	5076	5077
Hornblende	(brown							
	(green							
	(colourless	29.5	28	16.5	25.5	17	15.5	26
Garnet	(pink	4.5	4.5	3	6.5	3.5	16	6.5
Epidote				7	8			3.5
Clinozoisite		3.5	3.5	9	8	T		5.5
Zoisite		T						
	(colourless	20	18	19.5	12	27.5	20	18.5
Apatite	(coloured	3.5	3	3.5	2	4	3	2.5
Andalusite		1	T	T	1	T	1.5	2.5
	(red							
Rutile	(yellow	7	1	1	3	2.5	4.5	6.5
Sphene		13	4.5	7	9	8	9	8.5
	(blue							
	(brown	T	2	2	1.5	2	T	T
Tourmaline	(green	1	T	T	T	1.5	T	
	(pink		T		T		T	T
	(yellow	T	1		T	2		T
	(colourless			T				
Actinolite								
Allanite		T	T	2	2	5	2.5	4.5
Chlorite		2.5	3.5	10	2	11.5	14.5	5
	(Euhedral		T					
	(Euhedral	4.5	13.5	7	6.5	3	5	1.5
	(Subhedral	T*						
	(Subhedral	1.5	3.5	3	2	2	1	1
Zircon	(Well round	2*	6*	1.5*	1.5*	T*	2*	2*
	(well round	3	2	2	4	4.5	2	2.5
	(Anhedral					T*		
	(Anhedral	T	3	3.5	1.5	3	1.5	2
Staurolite			T		1.5	1	T	
Chloritoid				1	1			
Brookite		T						
Pyroxene								
	(red	3		2	4	4	7	2
Biotite	(brown	57	50	51	27	45	92	33
	(red	6	37	103	94	220	76	27
Opaque	(black	164	192	187	196	91	175	351

*: Hyacinth
T: less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-4

PERCENTAGES OF HEAVY MINERALS IN RAVENSCRAG BUTTE SECTION

		Frenchman		Ravenscrag							
Sample No.		5019	5021a	5022**	5023	5024**	5025	5026	5027**	5028	5029
	(brown										
Hornblende	(green										
	(colourless	4.5	17.5	16	13.5	17	12	21	22	15	9.5
Garnet	(pink	1	12.5	9	3	2	4.5	5.5	4	6	5
Epidote		52.5	23	19.5	23	26	27.5	20.5	18	27.5	38.5
Clinozoisite		10	6	15	13	17	7.5	6.5	15	5.5	5
Zoisite		1		T	T			T		T	
	(colourless	5.5	1.5		7		7	6		6.5	1
Apatite	(coloured	1	T		T		3	T		1	1
Andalusite			1	T	1	1	1.5			2	3
	(red	1							1		
Rutile	(yellow	T	10	10.5	2.5	7	5.5	9	5	4	8
Sphene		6	10	10	2.5	1	9.5	8	2	8	17.5
	(blue			T		1			1		
	(brown	1		2	2.5	5	5.5	2.5	4	3.5	1
Tourmaline	(green	1	3	3	6.5	7	3.5	3.5	4	5.5	4
	(pink		T	5	9.5	4	4	2.5	9	4	2
	(yellow			1.5	1		1.5	1.5	2		
	(colourless			T						1	T
Actinolite-Tremolite			T								
Allanite		1.5	3.5	1.5	1.5		1.5	1	2		
Chlorite		8.5	2	1	11		3.5	T		1.5	T
	(Euhedral										
	(Euhedral							1			T
	(Subhedral		1*								
	(Subhedral	1	1	T	T			1	2		1
Zircon	(Well round		1*	1.5*		2*	T*	5*	3*	3*	1*
	(Well round	1	2		T	1	T	1.5	3	2	T
	(Anhedral								1*		
	(Anhedral	T	1.5	1.5	T	6	1	2.5	2	3	
Staurolite		1	1.5			1					
Chloritiod		1		T			T				
Brookite		T				2					
	(red	T			1.5		4.5	T		6	
Biotite	(brown	5.5			1.5		9	1		14	
	(red	T	5	1.5	2		2		7	30	10.5
Opaque	(black	18.5	102.5	49.5	64	83	54.5	77	91	69.5	73.5

* Hyacinth
** Treated with HCl
T: less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

[illegible]

TABLE A-5

PERCENTAGES OF HEAVY MINERALS IN RAVENSCRAG SECTION

Sample No.		5401	5402	5403	5404	5405	5406	5407	5408
					Frenchman				
Hornblende	(brown	20	23.5	17	19	12		10	18
	(green	57.5	55	61.5	54	52	10	39.5	45
Garnet	(colourless	1	T	1.5	2.5	5	10	7.5	5
	(pink	3	2	2.5	2.5		2.5	8	4.5
Epidote		6	11.5	8	9	10.5	34.5	16	12.5
Clinozoisite		3	3.5	1.5	3.5	6	18.5	6	3
Zoisite									
Apatite	(colourless	1		T	1	2.5	2.5	T	1
	(coloured						1		
Andalusite			T						
Rutile	(red				T				
	(yellow	T	T	1	T	1	T	1	1.5
Sphene		3	T	T	3.5	2	6	5.5	2
Tourmaline	(blue								
	(brown		1						T
	(green	T			T				
	(pink					T		1	
	(yellow			1			T		
	(colourless								
Actinolite		T		T	1.5	1.5		T	1.5
Allanite				1.5			T	1	1.5
Chlorite		1		T					
Zircon	(Euhedral						T*		
	(Euhedral	1.5		1.5	T	2	3	T	T
	(Subhedral						1*		
	(Subhedral		T			1.5	3	1	
	(Well round		T*	T*	T*	2*	3*		1*
	(Well round	T		T	T		1		T
	(Anhedral						T*		T*
	(Anhedral						T	1.5	T
Staurolite		T					T	1	1
Chloritoid		T				T	T		
Brookite									
Pyroxene			T		T				
Biotite	(red			1					
	(brown	3	2	2	5				1
Opaque	(red	3	2	1	38	2	3	2	1
	(black	50	35	48	39	73	122	94	78

*: Hyacinth
T: less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-6

PERCENTAGES OF HEAVY MINERALS IN OLD MAN ON HIS BACK PLATEAU SECTION

				Frenchman			
Sample No.		5409	5410**	5411	5412	5413**	5414
	(brown	2.5	2	8	6.5	13.5	32.5
Hornblende	(green	20	31	18.5	32.5	49	40
	(colourless	7	11	7	11.5	5	2.5
Garnet	(pink	7.5	7.5	4.5	7	2.5	3
Epidote		34	16.5	37	20	12.5	8
Clinozoisite		5	5.5	3.5	7	6.5	1
Zoisite		T		1			
	(colourless	2		1.5	1.5		T
Apatite	(coloured	1.5		2	1.5		
Andalusite		1					
	(red						
Rutile	(yellow	2	2	1.5		1.5	T
Sphene		9	11	5	6	2	
	(blue				T		
	(brown	T		T			
Tourmaline	(green			1			
	(pink						
	(yellow		T	T			T
	(colourless						
Actinolite						3	1.5
Allanite		1	2	T	1	T	
Chlorite		T	1	T	T		1.5
	(Euhedral						
	(Euhedral	2	2	2	T	2	
	(Subhedral					T*	
	(Subhedral	1	1.5	1	1	T	
Zircon	(Well round	1.5*	2.5*	1.5*	1*		T*
	(Well round		2	1	2	1	
	(Anhedral						
	(Anhedral	1	1.5	1.5			
Staurolite			T				1
Chloritoid				T			
Brookite							
Glaucophane		T					
Pyroxene							5.5
	(red				2		
Biotite	(brown			2	18.5		
	(red	4	2	2	4.5		2
Opaque	(black	91.5	177	105	100	39	25.5

*: Hyacinth
**: Treated with HCl
T: less than 1%
Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-7

PERCENTAGES OF HEAVY MINERALS IN ADAMS CREEK SECTION

		Frenchman			Ravenscrag				
Sample No.		5030	5031	5032	5033	5034	5035	5036**	5037
Hornblende	(brown	8.5	29	10					
	(green	45.5	38.5	27					
Garnet	(colourless	7.5	5.5	9.5	14.5	9.5	11.5	13.5	8
	(pink	3.5	7.5	1.5	6.5	5	6	7.5	4
Epidote		13.5	5.5	22	15	21	18	18.5	18
Clinozoisite		6	3	8.5	1	3	6	11	6
Zoisite			T		1		1.5	T	
Apatite	(colourless	2	1.5	2.5	9.5	16.5	8.5		14
	(coloured	T			1	1			
Andalusite		3	2	3	2	1	1	3.5	1
Rutile	(red					T			
	(yellow			2	4.5	10	15	4	7
Sphene		2	2.5	4.5	9	7	9.5	10.5	4.5
Tourmaline	(blue				T	1			T
	(brown			1	T	2	1	6	2.5
	(green	T			1.5	3	1.5	9	1
	(pink				2.5	3	3	4.5	2.5
	(yellow				1	1.5	1	1.5	1
	(colourless		T			T		T	
Actinolite-Tremolite		2		T	T		T		
Allanite					1.5	1.5	1		T
Chlorite		T		T				2.5	T
Zircon	(Euhedral								
	(Euhedral	T	1	1.5	6	1	2.5	T	7.5
	(Subhedral					T*			4*
	(Subhedral	1.5			2	1	1	1	4.5
	(Well round			2.5*	6.5*	3*	4.5*	1*	8*
	(Well round		1	1	9.5	5	4	3.5	3.5
	(Anhedral							T*	
	(Anhedral	1.5	1	2.5	2	2	3	T	1
Staurolite									
Chloritoid		1							
Brookite									
Biotite	(red			T				1	
	(brown			1		4		6.5	
Opaque	(red	26.5	7.5	7	15	4.5	50	2	38
	(black	100.5	88	84	123	98	170	79	160.5

*:Hyacinth
**: Treated with HCl
T: less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-8

PERCENTAGES OF HEAVY MINERALS IN ELKWATER HIGHWAY 48 ROAD SECTION

Sample No.		5415	5416	5417	5418	Frenchman 5419	5420	5421	5422	5423
	(brown			T	1.5	T	1	1	1	2.5
Hornblende	(green	T	1.5	18	17.5	7.5	20	16.5	12.5	34
	(colourless	28	25.5	12.5	16.5	19.5	15	14	14	15
Garnet	(pink	4	2	1	1.5	5.5	8	2.5	2.5	2.5
Epidote		11	5	13.5	15.5	18.5	14	12	15	12.5
Clinozoisite		9.5	12.5	11.5	10	12.5	5.5	7.5	7	4.5
Zoisite										
	(colourless	5	14	4.5	8.5	6	4	7.5	5.5	3
Apatite	(coloured	T	T		T	T	T	T	T	1
Andalusite		T			T					
	(red				1	T	1	T	1	T
Rutile	(yellow	7	1	1		1.5	2.5	1.5	2.5	3.5
Sphene		8.5	16.5	7.5	10	14	8	8	10.5	3
	(blue				T					
	(brown	T	T				T	1	T	
Tourmaline	(green	T	2	1.5		T	1	1.5	1	1.5
	(pink	1.5	3.5	3	2	2.5	1.5	1		3
	(yellow	1	2.5	1.5		1		2.5	T	1.5
	(colourless							1		
Actinolite			T	6	2	1.5	2	4.5	1.5	2.5
Allanite		1	4	T	2.5	2	2.5	3	3	1
Chlorite		2	2	2.5	2.5	1.5				T
	(Euhedral								T*	
	(Euhedral	T	1	1.5	2	1	1.5	1	2	1
	(Subhedral	1*		1*	T*		T*		1*	
	(Subhedral	4	T	3.5	1	T	2.5	1.5	2	T
Zircon	(Well round	6.5*	4*	5.5*	2.5*	1	4.5*	7*	7*	2*
	(Well round	2.5	1	2	1	1.5	3.5	4	5.5	T
	(Anhedral	1.5*		1*			T*	T*	1*	
	(Anhedral	2.5		T					2	T
Staurolite		T			T				T	
Chloritoid										1
Brookite										
Pyroxene										1.5
	(red		1							
Biotite	(brown	6	2			1				
	(red	13	2	1	7	3	4	6	4	4
Opaque	(black	110	60	109	69	92	135	119	130	66

*: Hyacinth
T: less than 1%

Biotite and opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-8

PERCENTAGES OF HEAVY MINERALS IN ELKWATER HIGHWAY 48 ROAD SECTION

		Ravenscrag							
Sample No.		5430	5431	5432	5433	5434	5435	5436	5437
Hornblende	(brown								
	(green								
	(colourless	7.5	14.5	19.5	18.5	21	22.5	14.5	10
Garnet	(pink	1	4	3	2	1	1	1.5	3.5
Epidote		22.5	19	19.5	22.5	20.5	20.5	20	14.5
Clinozoisite		9.5	12.5	11	17	18	16.5	17	8
Zoisite									
	(colourless	14.5	10.5	5.5	2	T	1		
Apatite	(coloured	1	T						
Andalusite				T	1				1.5
	(red		T	T	1	1		2.5	3
Rutile	(yellow	1	2.5	5	T		1.5		1
Sphene		6	13	10	T	T		T	T
	(blue	T	T	T	2	1		1.5	1
	(brown	2	T	T	T	2.5	1	1.5	1
	(green	3	2.5	4	6.5	8.5	2.5	5	5
Tourmaline	(pink	8	5.5	4.5	8	10	5.5	8	7
	(yellow	1.5	T	1.5	6	1.5	5	1	3.5
	(colourless			1	1	T			
Actinolite		1.5		1	2	T	1.5		T
Allanite		1.5	T	3.5	T	2	1	T	3.5
Chlorite		3.5	T	T			T		
	(Euhedral				T*				T*
	(Euhedral	1	1	2.5	T	1	4.5	4.5	7
	(Subhedral	T*	T*		T*	1*	3*	2*	1.5*
	(Subhedral	1	1	1	2.5	2.5	5	2	5
Zircon	(Well round	5*	5.5*	2.5*	3*	4.5*	6.5*	13*	10*
	(Well round	4.5	4	1	1	1.5	1	5	11
	(Anhedral	T*	T*						T*
	(Anhedral	1.5		1.5	T				1
Staurolite		1							
Chloritoid									
Brookite									
Pyroxene									
	(red	1		8	1	3	2		
Biotite	(brown			34	22	12	4		5
	(red	3	2	12	13	10	17	12	10
Opaque	(black	110	164	149	19	38	42	121	68

*: Hyacinth
T: less than 1%

Biotite and opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-9

PERCENTAGES OF HEAVY MINERALS IN ELKWATER CAMP GROUND SECTION

Sample No.		5039	5040	5041	5042	5043	5044	5045	5046
	(brown	2	2	1.5	1.5	3	17.5	24	4
Hornblende	(green	7	13	1	4	32	67	64.5	14
	(colourless	7.5	5	13	10	7.5	1	T	23
Garnet	(pink	10.5	2.5	3	9	3.5	1	1	8
Epidote		20.5	37	27.5	25.5	28	2.5	3.5	9
Clinozoisite		10	8.5	8	12	10.5	3.5	1.5	7
Zoisite		T	2		1.5				T
	(colourless	10	4	6.5	5.5		2	T	3
Apatite	(coloured	T	1.5	1.5	T				
Andalusite		2	1.5	1	1.5	2	T	T	1.5
	(red								1.5
Rutile	(yellow	T	1	1.5	T				2
Sphene		5.5	10.5	13.5	12.5	3	1	T	10
	(blue				T				
	(brown			T					1.5
Tourmaline	(green	T		1	1				1.5
	(pink	T		1	T				1.5
	(yellow		T	1					1.5
	(colourless								
Actinolite		1	2	1	1	5	2.5	1.5	3
Allanite		T			1				1.5
Chlorite		5.5	1	2.5	3.5				1.5
	(Euhedral								
	(Euhedral	8.5	3	4.5	4.5	2		T	1.5
	(Subhedral			T*					
	(Subhedral	1.5	2	1.5	1	T	T	1	
Zircon	(Well round	1*	T*	T*	1*	1*			T*
	(Well round	2	1	5	T	1.5			T
	(Anhedral	T*		T*					
	(Anhedral	2	1.5	2.5	1	T	T		T
Staurolite									
Chloritoid									T
Brookite									
Glaucophane					T				
	(red		1		1		2		1
Biotite	(brown	4	1	6	1	1			
	(red	19	6	21	25	4	10	5	6
Opaque	(black	211	225	186	104	34	11	34	54

*: Hyacinth

T: less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

[illegible]

TABLE A-10

PERCENTAGES OF HEAVY MINERALS IN ELKWATER SCENIC ROAD SECTION

		Frenchman		Ravenscrag
Sample No.		5424	5425	5438
Hornblende	(brown	3	4.5	
	(green	49.5	48.5	
Garnet	(colourless	4.5	6	13
	(pink	5	1.5	5
Epidote		12.5	9	11.5
Clinozoisite		8.5	11	9.5
Zoisite				
Apatite	(colourless	3	3.5	11.5
	(coloured	T	1	T
Andalusite				
Rutile	(red	1		T
	(yellow			6.5
Sphene		5	3.5	12.5
Tourmaline	(blue			
	(brown		T	1
	(green		1	3.5
	(pink	T	T	1
	(yellow	1	1	1.5
	(colourless			
Actinolite		3	3	T
Allanite				2
Chlorite		T		T
Zircon	(Euhedral			
	(Euhedral	1	1.5	4
	(Subhedral			
	(Subhedral	1	1.5	4.5
	(Well round		1*	4*
	(Well round		1.5	5.5
	(Anhedral			
	(Anhedral			T
Staurolite		T		1
Chloritoid				
Brookite				
Biotite	(red			
	(brown		1	1
Opaque	(red	48	23	15
	(black	50	69	88

*: Hyacinth
T: less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

TABLE A-11

PERCENTAGES OF HEAVY MINERALS IN EAGLE BUTTE SECTION

Sample No.		5426	5427	5428	5429
			Frenchman		
	(brown				
Hornblende	(green			T	
	(colourless	11	12	11	26.5
Garnet	(pink	7	12	10	6.5
Epidote		28.5	29.5	26.5	22.5
Clinozoisite		11.5	13.5	16	14
Zoisite					T
	(colourless	2	3	5	5
Apatite	(coloured	1	1.5	T	1.5
Andalusite		T	1	T	T
	(red				
Rutile	(yellow	3.5	2	4.5	1.5
Sphene		12	9	10.5	8
	(blue				
	(brown				
	(green				
Tourmaline	(pink	T	1	T	T
	(yellow	T	1	1.5	1
	(colourless				
Actinolite		1			
Allanite		1	1	T	T
Chlorite		T	2.5		1
	(Euhedral				
	(Euhedral	5.5	3.5	5	3
	(Subhedral		T*		T*
	(Subhedral	5	2.5	1.5	3.5
Zircon	(Well round	4 *	2.5 *	1 *	1 *
	(Well round	3.5	T	1.5	2
	(Anhedral			T*	
	(Anhedral	1	1	1.5	T
Staurolite		T	T	1	
Chloritoid					
Brookite					
Glaucophane				T	
	(red	1	2		
Biotite	(brown	6	8	2	5
	(red	11	24	48	36
Opaque	(black	253	180	145	162

*: Hyacinth
T: less than 1%

Biotite and Opaque: grains accompanying the 100 non-opaque minerals.

PLATE 1

Thin-Section Photomicrographs

Figure 1	Authigenic quartz overgrowth on well rounded quartz grain surrounded and wedged apart by calcite cement. Note calcite replacement of authigenic quartz overgrowth in margin. Nicols crossed ; X62 ; Sample 5408.
Figure 2	Detrital plagioclase surrounded, replaced and wedged apart by calcite cement. Nicols crossed ; X160 ; Sample 5076.
Figure 3	Calcite replacing center of chert grain (centre)and margin of plagioclase (left). Nicols crossed ; X160 ; Sample 5076.
Figure 4	Detrital plagioclase replaced and wedged apart by calcite cement (centre) and calcite replacement of quartz (lower left). Nicols crossed; X62; Sample 5076.
Figure 5	Authigenic quartz overgrowth on quartz grain distinguished by thin line of imputities. Nicols crossed ; X62 ; Sample 5063.
Figure 6	Fibrous calcite cement developed perpendicularly to surface of grains and granular calcite cement between grains. Nicols crossed ; X62 ; Sample 5408.
Figure 7	Development of authigenic dolomite between clastic grains and calcite cement. Nicols not crossed ; X62 ; Sample 5068A.
Figure 8	Same as 7, but Nicols crossed.

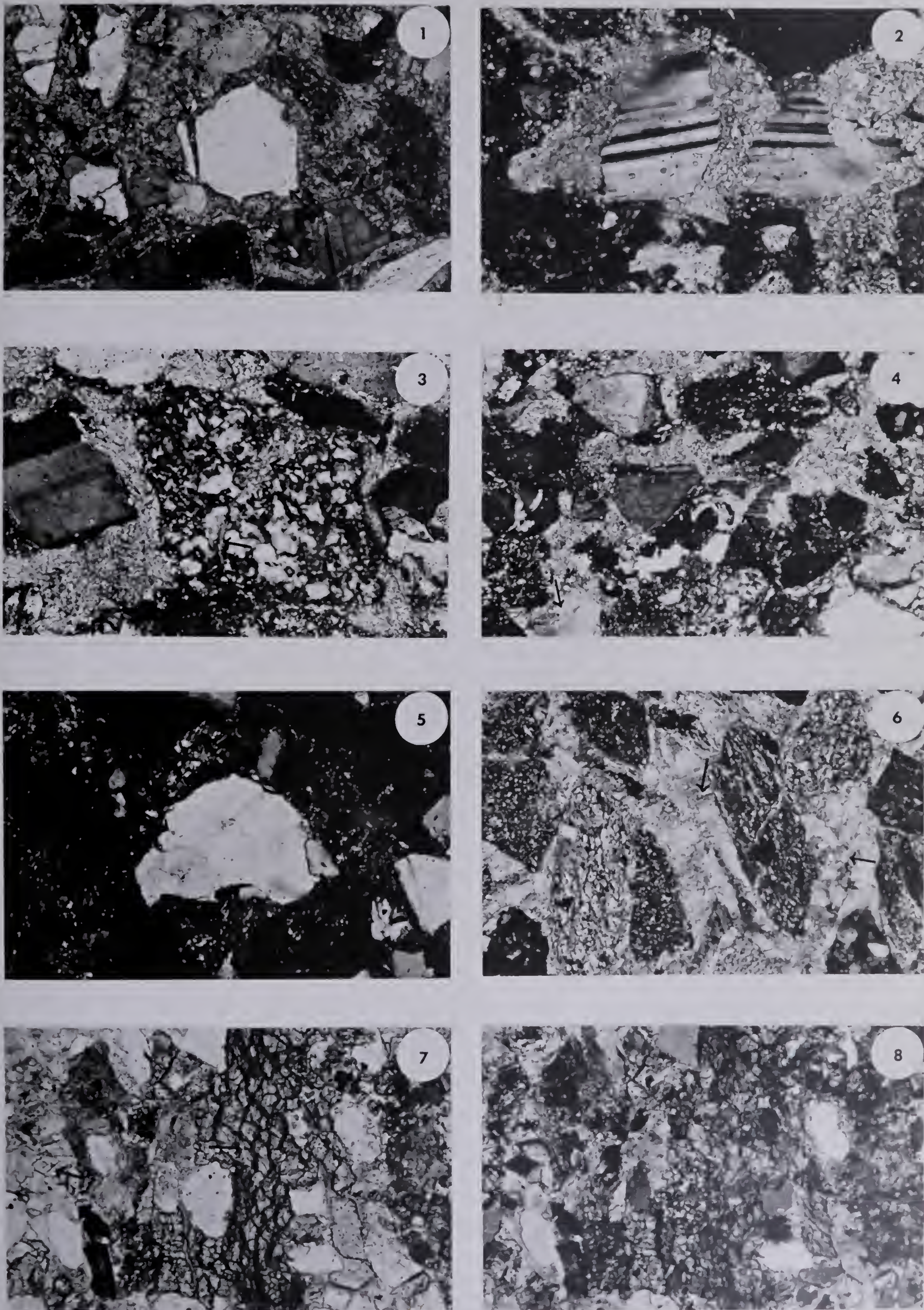

PLATE I.

PLATE II

Thin-Section Photomicrographs

Figure I — Myrmekitic texture showing vermicular forms (centre). Sericitization of plagioclase displaying numerous sericite flakes (upper left). Nicols crossed ; X160 ; Sample 5073.

Figure 2 — Volcanic quartz grain showing crystal faces. Nicols crossed ; X62 ; Sample 5408.

Figure 3 — Volcanic rock fragment showing lath-like feldspar crystals. Note fibrous calcite cement. Nicols crossed ; X160 ; Sample 5408.

Figure 4 — Low grade metamorphic rock fragment surrounded by fibrous calcite cement. Nicols crossed ; X160 ; Sample 5408.

Figure 5 — Thin films of authigenic clay between clastic grains. Nicols crossed ; X62 ; Sample 5063.

Figure 6 — Segregated mass of calcite cement. Nicols crossed ; X62 ; Sample 5064.

Figure 7 — Separation of sand grains by continuous mass of calcite cement. Nicols crossed ; X62 ; Sample 5401.

Figure 8 — Note subparallel orientation of elongate grains. Nicols crossed ; X25 ; Sample 5408.

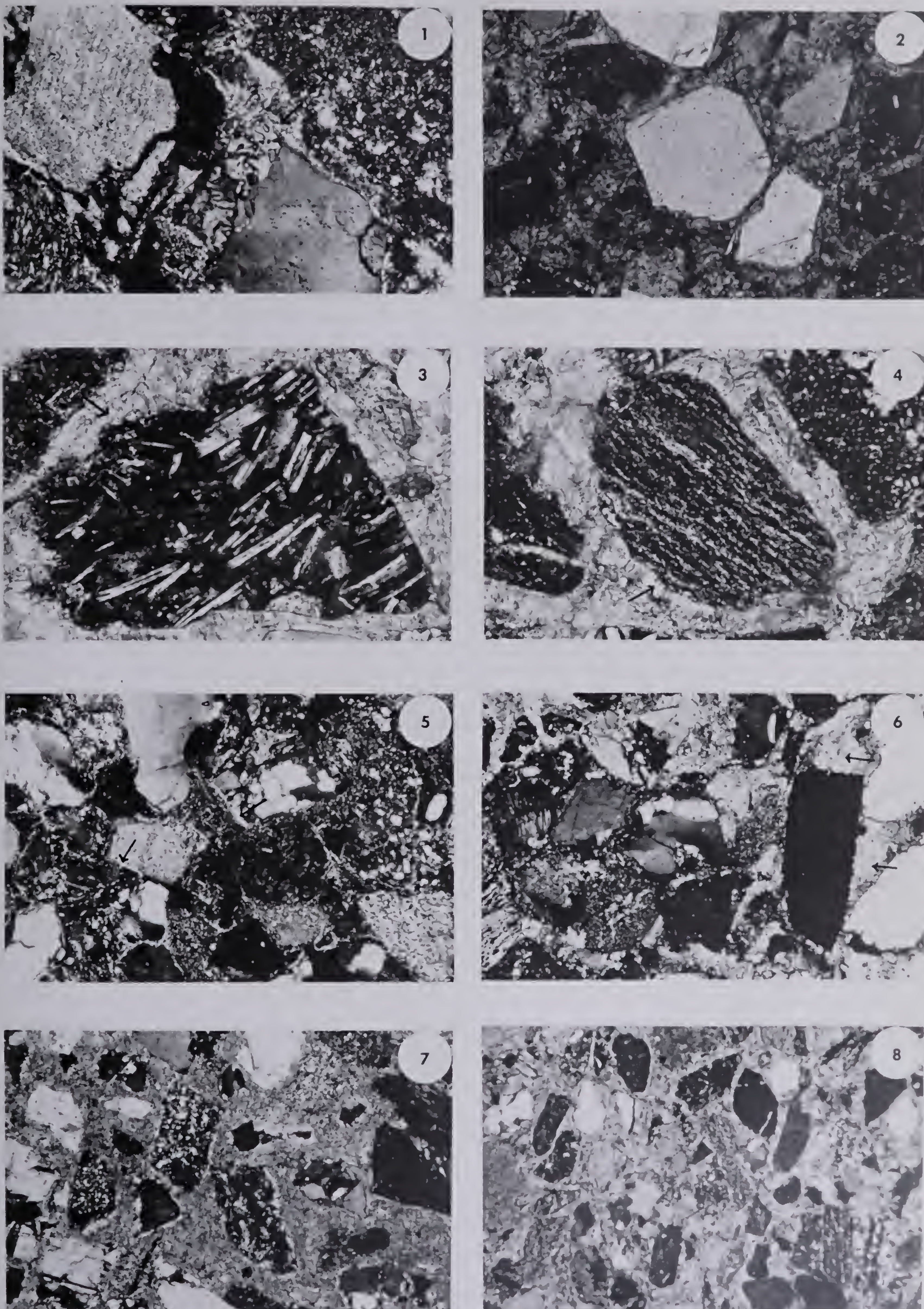

PLATE II.

PLATE III

Heavy minerals from Frenchman and Ravenscrag sandstones

Figure 1 Zircon - Twinned, colourless, euhedral, prismatic, pyramidal termination, apatite(?) inclusions; X82; Sample 5433, Ravenscrag.

Figure 2 Zircon - Twinned, colourless, euhedral, pyramidal terminations; X82; Sample 5037, Ravenscrag.

Figure 3 Zircon - Composite crystals, colourless, euhedral, prismatic, pyramidal terminations, black speck inclusions; X62; Sample 5036, Ravenscrag.

Figure 4 Zircon - Twinned, colourless, euhedral, unidentified mineral inclusion ; X82 ; Sample 5421, Frenchman.

Figure 5 Zircon - Twinned, colourless, euhedral, prismatic, black speck inclusions ; X82 ; Sample 5033, Ravenscrag.

Figure 6 Zircon - Twinned, colourless, euhedral, pyramidal terminations, black speck inclusions ; X82 ; Sample 5406, Frenchman.

Figure 7 Zircon - Twinned, colourless, euhedral, inclusion free ; X82 ; Sample 5433, Ravenscrag.

Figure 8 Zircon - Twinned, colourless, euhedral, prismatic, pyramidal terminations, apatite(?) and black speck inclusions ; X82 ; Sample 5427, Frenchman.

Figure 9 Zircon - Twinned, colourless, euhedral, black speck inclusions ; X82 ; Sample 5413, Frenchman.

Figure 10 Zircon - Composite crystals, colourless, euhedral, Apatite(?)and black speck inclusions ; X84 ; Sample 5428, Frenchman.

Figure 11 Zircon - Twinned(?), colourless, nucleus of opaque mineral ; X82 ; Sample 5428, Frenchman.

Figure 12 Zircon - Composite crystals, colourless, rounded, inclusion present ; X82 ; Sample 5429, Frenchman.

Figure 13 Zircon - Twinned, colourless, black speck abd bubble inclusions ; X82 ; Sample 5427, Frenchman.

Figure 14 Hyacinth - Well rounded, outgrowth, inclusion free ; X82 ; Sample 5427, Frenchman.

Figure 15 Zircon - Colourless, well rounded, outgrowth, black speck inclusions ; X82 ; Sample 5033, Ravenscrag.

Figure 16 Hyacinth - Well rounded, outgrowth, inclusion free ; X82 ; Sample 5414, Frenchman.

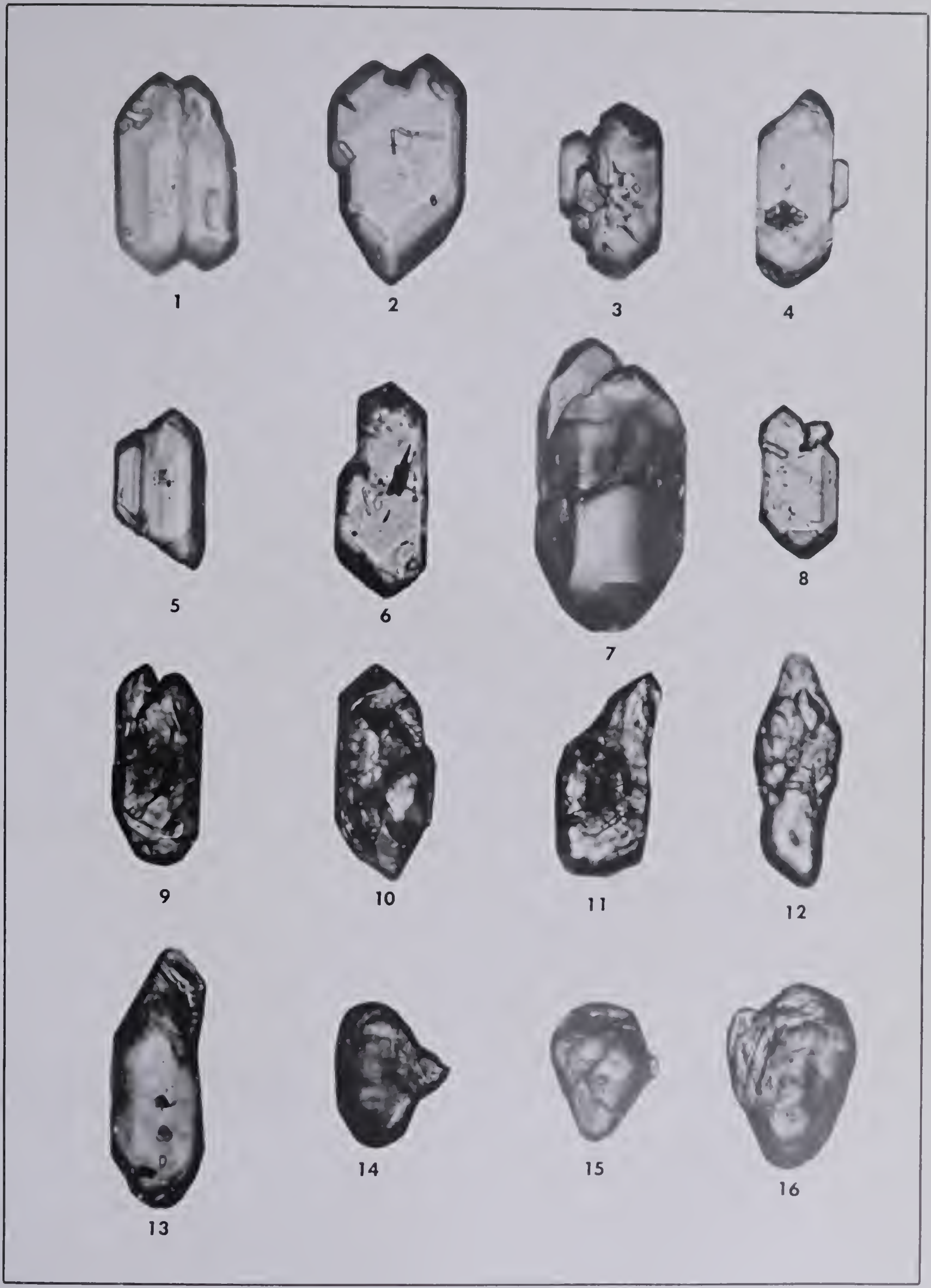

PLATE III.

PLATE IV

Heavy minerals from Frenchman and Ravenscrag sandstones

Figure 1 Zircon - Colourless, euhedral, elongate, prismatic, pyramidal termination, apatite(?)inclusions ; X64; Sample 5427, Frenchman.

Figure 2 Zircon - Colourless, euhredal, prismatic, pyramidal terminations, apatite(?) and black speck inclusions ; X102 ; Sample 5415, Frenchman.

Figure 3 Zircon - Colourless, euhedral, apatite(?) inclusions ; X102 ; Sample 5426, Frenchman.

Figure 4 Zircon - Colourless, euhedral, elongate, prismatic, apatite(?) inclusions ; X82 ; Sample 5406, Frenchman.

Figure 5 Zircon - Colourless, euhedral, prismatic terminations, black speck inclusions, X82 ; Sample 5042, Frenchman.

Figure 6 Zircon - Colourless, euhedral, bubble and apatite(?) inclusions ; X82, Sample 5037, Ravenscrag.

Figure 7 Zircon - Colourless, euhedral, prismatic, pyramidal terminations, inclusion free ; X82 ; Sample 5410, Frenchman.

Figure 8 Zircon - Colourless, euhedral, prismatic, pyramidal terminations, bubble inclusions ; X82 ; Sample 5035, Ravenscrag.

Figure 9 Zircon - Colourless, euhedral, apatite(?) and black speck inclusions ; X82 ; Sample 5418, Frenchman.

Figure 10 Zircon - Colourless, euhedral, zoned, black speck inclusions ; X82 ; Sample 5406, Frenchman.

Figure 11 Zircon - Colourless, euhedral, elongate, prismatic,apatite(?) inclusions ; X82 ; Sample 5037, Ravenscrag.

Figure 12 Zircon - Colourless, euhedral, elongate, prismatic, apatite(?) inclusions ; X82 ; Sample 5037, Ravenscrag.

Figure 13 Zircon - Colourless, euhedral, prismatic, pyramidal terminations, black speck inclusions ; X82 ; Sample 5423, Frenchman.

Figure 14 Zircon - Colourless, subhedral, subrounded, black speck inclusions ; X82 ; Sample 5427, Frechman.

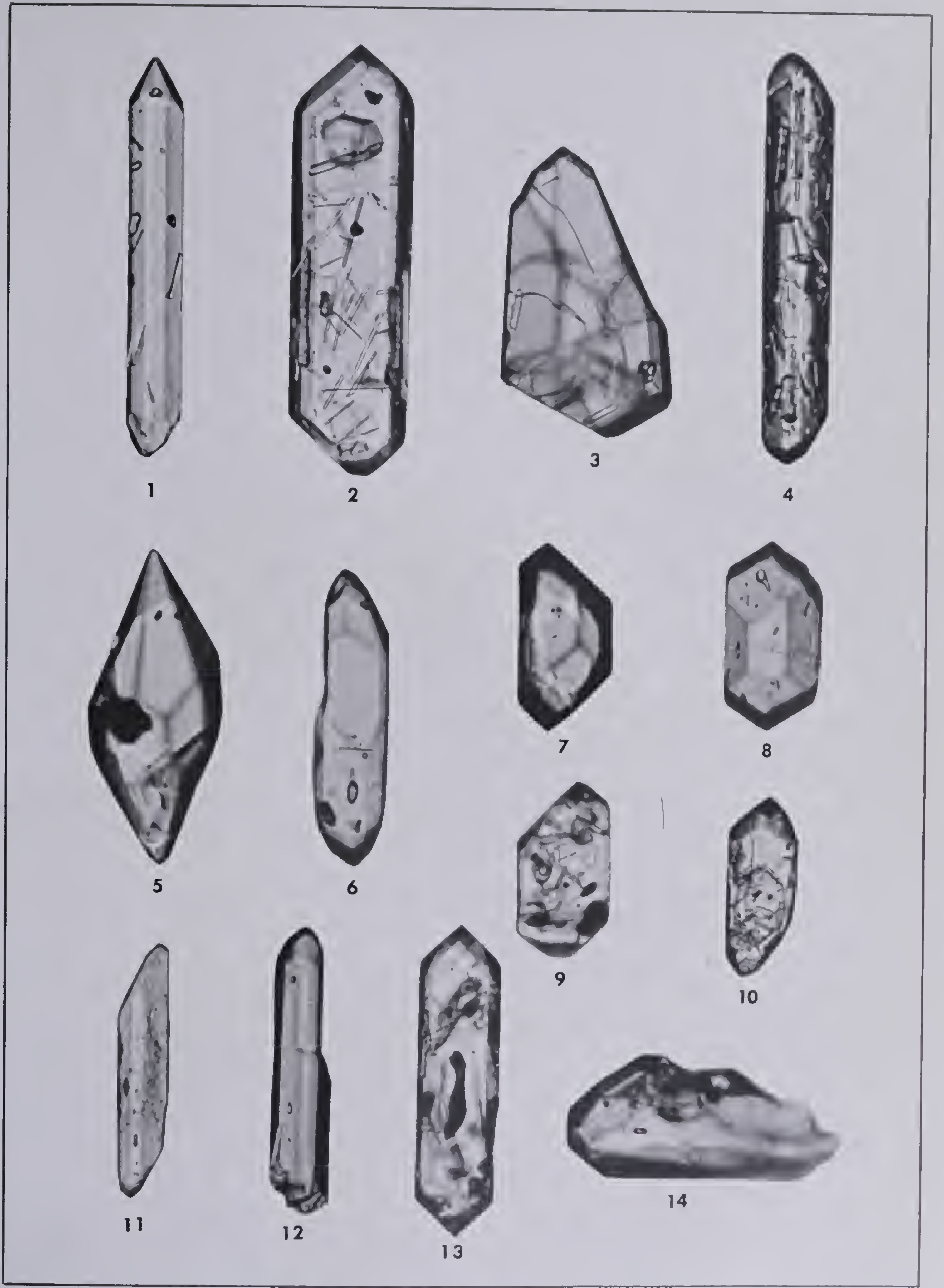

PLATE IV.

PLATE V

Heavy minerals from Frenchman sandstones

Figure 1	Hyacinth - Euhedral, prismatic, rounded, zoned, inclusion present ; X82 ; Sample 5031.
Figure 2	Zircon - Colourless, euhedral, overgrowth(?), apatite(?) and black speck inclusions ; X102 ; Sample 5415.
Figure 3	Zircon - Colourless, euhedral, nucleus of opaque mineral, X64 ; Sample 5031.
Figure 4	Zircon - Colourless, angular, corroded(?),bubble and black speck inclusions ; X82 ; Sample 5030.
Figure 5	Zircon - Colourless, euhedral, prisms, pyramids and pinacoids faces, apatite(?) and black speck inclusions ; X82 ; Sample 5031.
Figure 6	Hyacinth - Well rounded, inclusion free ; X102 ; Sample 5415.
Figure 7	Zircon - Colourless, well rounded, inclusion free ; X82 ; Sample 5420.
Figure 8	Sphene - Subhedral, angular, apatite and bubble inclusions ; X82 ; Sample 5421.
Figure 9	Sphene - Angular, zircon, apatite and black speck inclusions ; X102 ; Sample 5426.
Figure 10	Sphene - Rounded, bubble inclusions ; X82 ; Sample 5046.
Figure 11	Sphene - Rounded, bubble and black speck inclusions ; X82 ; Sample 5039.
Figure 12	Sphene - Euhedral, prismatic, black speck inclusions ; X82 ; Sample 5419.
Figure 13	Garnet - Euhedral, dodecahedral crystal faces, inclusion free ; X82 ; Sample 5415.
Figure 14	Garnet - Rounded, dusty material inclusions ; X82 ; Sample 5418.
Figure 15	Garnet - Euhedral, inclusion free ; X82 ; Sample 5417.
Figure 16	Garnet - Angular, inclusion free, X82 ; Sample 5418.

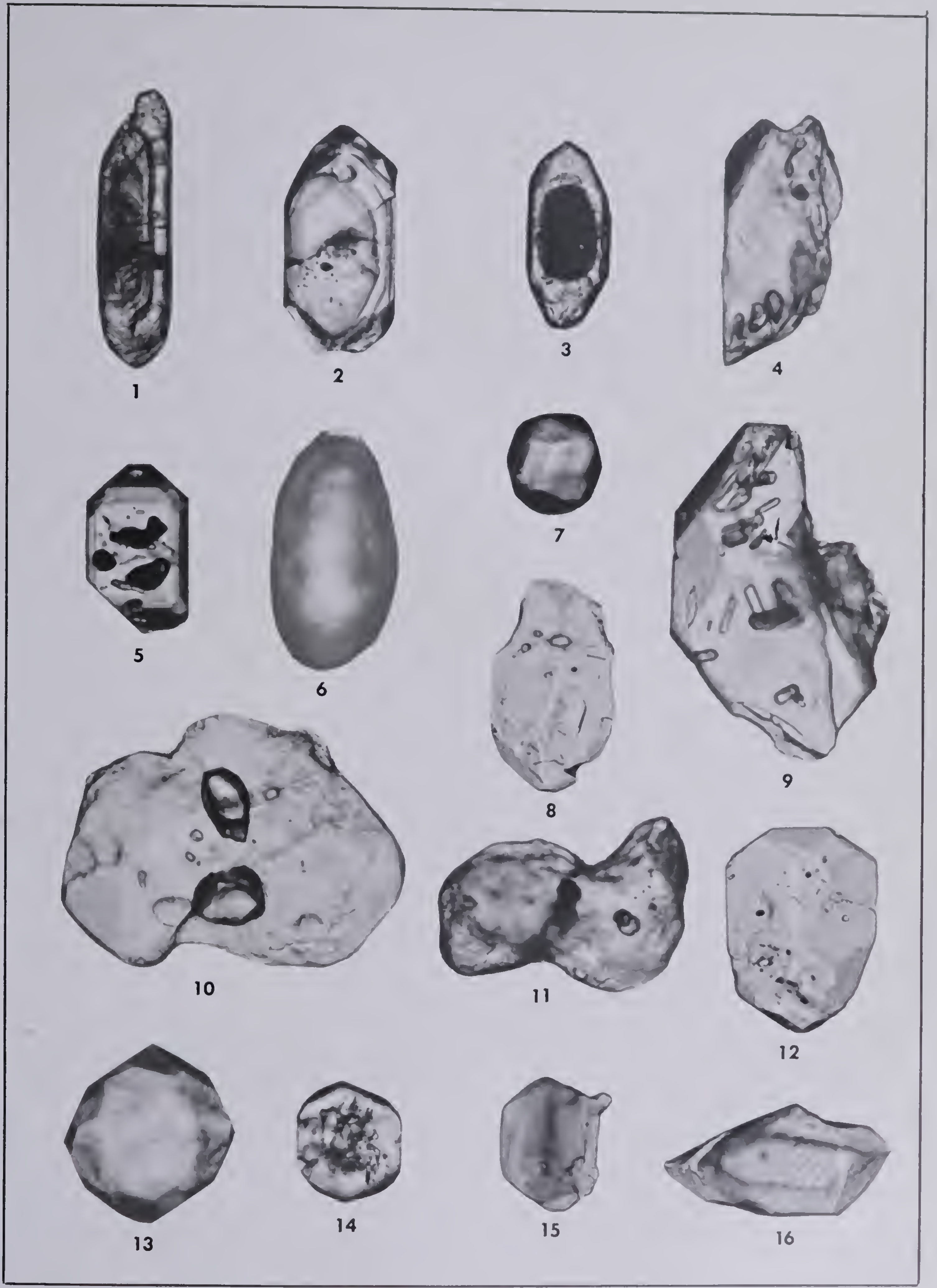

PLATE V.

PLATE VI

Heavy minerals from Frenchman sandstones

Figure 1 Tourmaline - Well rounded, inclusion free; X82 ; Sample 5422.

Figure 2 Tourmaline - Elongate, prismatic, unidentified mineral inclusions ; X82 ; Sample 5032.

Figure 3 Tourmaline - Euhedral, prismatic, bubble and apatite(?) inclusions ; X82 ; Sample 5416.

Figure 4 Tourmaline - Euhedral, prismatic, bubble inclusions ; X82 ; Sample 5420.

Figure 5 Rutile - Rounded, prismatic, inclined striations, inclusion free ; X82 ; Sample 5421.

Figure 6 Rutile - Subrounded, prismatic, inclusion free ; X82 ; Sample 5421.

Figure 7 Rutile - Angular, inclusion free ; X82 ; Sample 5419.

Figure 8 Allanite - Subrounded, prismatic, inclusion free, X82 ; Sample 5426.

Figure 9 Collophane - Well rounded, inclusion free ; X82 ; Sample 5423.

Figure 10 Apatite - Rounded, authigenic overgrowth(?), prismatic, inclusion free ; X82 ; Sample 5421.

Figure 11 Apatite - Well rounded, brownish in centre, colourless in margin, inclusion free ; X82 ; Sample 5421.

Figure 12 Apatite - Subrounded, brownish stripes, dusty inclusions ; X82 ; Sample 5418.

Figure 13 Clinozoisite - Subrounded, elongate, black speck inclusions ; X82 ; Sample 5420.

Figure 14 Staurolite - Subrounded, zircon(?) and bubble inclusions ; X82 ; Sample 5414.

Figure 15 Barite - Angular, dusty inclusions ; X82 ; Sample 5410.

Figure 16 Clinozoisite - Angular, strongly etched, inclusion free ; X82 ; Sample 5426.

Figure 17 Epidote - Angular, strongly etched, bubble(?) inclusions ; X82 ; Sample 5426.

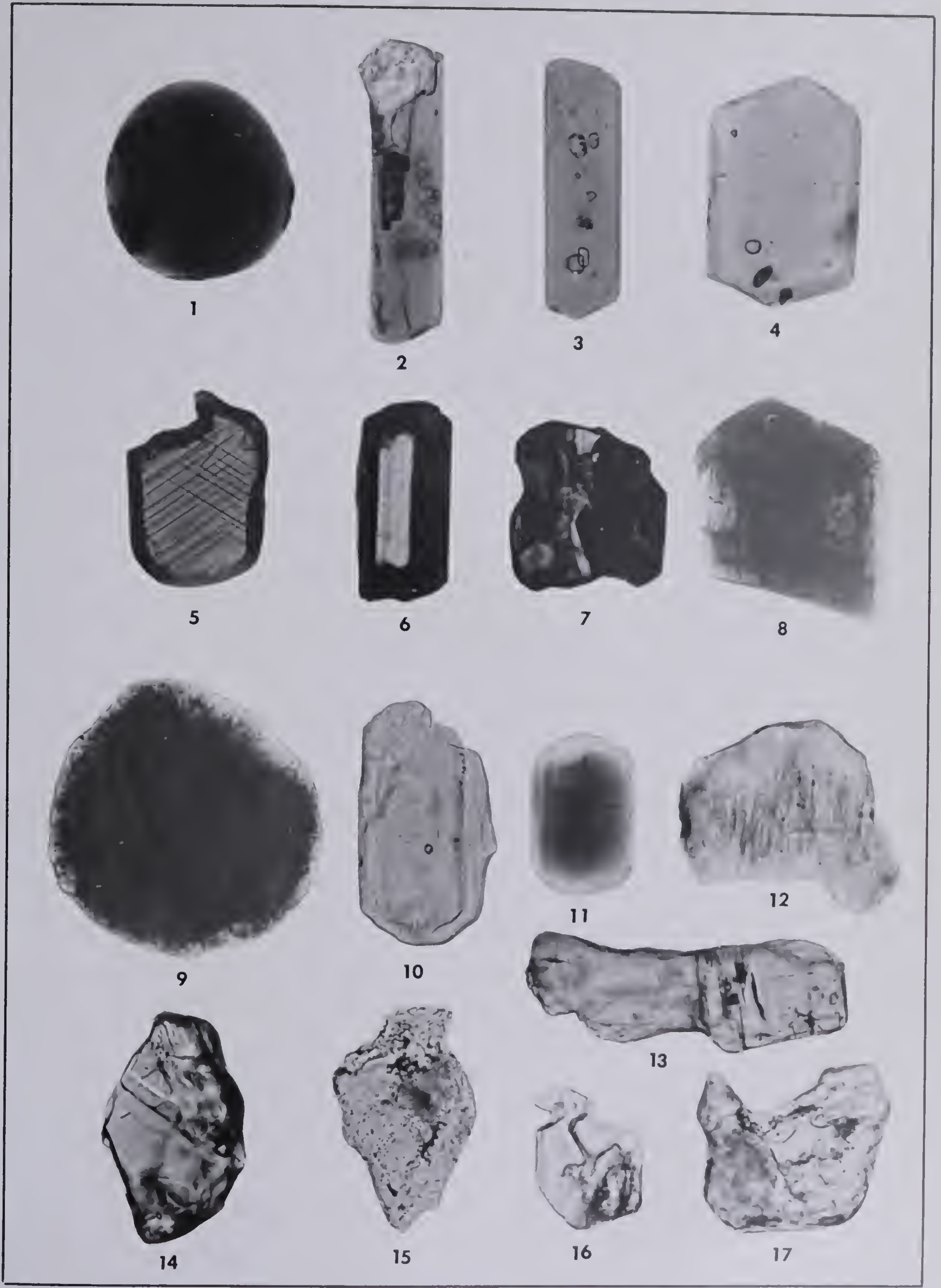

PLATE VI.

PLATE VII

Heavy minerals from Frenchman and Upper Edmonton sandstones

Figure 1 Hornblende - Angular, strongly etched, hacksaw terminations, inclusion free ; X82 ; Sample 5407, Frenchman.

Figure 2 Hornblende - Angular, strongly etched, hacksaw terminations, inclusion free ; X82 ; Sample 5043, Frenchman.

Figure 3 Hornblende - Angular, slightly etched, zircon(?)black speck and bubble inclusions ; X82 ; Sample 5031, Frenchman.

Figure 4 Hornblende - Angular, prismatic, devoid of etching, inclusion free ; X82 ; Sample 5407, Frenchman.

Figure 5 Tremolite - Angular, prismatic, etched, spine termination, inclusions present ; X82 ; Sample 5041, Frenchman.

Figure 6 Tremolite - Angular, etched, inclusion free ; X82 ; Sample 5418, Frenchman.

Figure 7 Chlorite - Rounded, black speck inclusions ; X82 ; Sample 5418, Frenchman.

Figure 8 Glaucophane - Subrounded, prismatic, inclusions present ; X82 ; Sample 5042, Frenchman.

Figure 9 Zircon - Colourless, euhedral, pyramidal terminations, apatite(?) and black speck inclusions ; X82 ; Sample 5072, Edmonton.

Figure 10 Zircon - Twinned(?), colourless, euhedral, pyramidal terminations, apatite(?) inclusions ; X82 ; Sample 5072, Edmonton.

Figure 11 Zircon - Colourless, euhedral, zoned, apatite(?) and black speck inclusions ; X82 ; Sample 5067, Edmonton.

Figure 12 Zircon - Twinned, colourless, euhedral, inclusion free ; X82 ; Sample 5076, Edmonton.

Figure 13 Zircon - Twinned(?), colourless, euhedral, apatite(?) and bubble inclusions, pyramidal termination, X82 ; Sample 5071, Edmonton.

Figure 14 Zircon -Yellowish brown, composite euhedral grains, inclusion free ; X82 ; Sample 5071 , Edmonton.

Figure 15 Zircon - Colourless, euhedral. inclusion free ; X82 ; Sample 5074, Edmonton.

Figure 16 Hyacinth - Well rounded, bubble inclusions ; X82 ; Sample 5064, Edmonton.

Figure 17 Hyacinth - Well rounded, inclusion free ; X82 ; Sample 5073, Edmonton.

PLATE VII.

PLATE VIII

Heavy minerals from Upper Edmonton sandstones

Figure 1 Apatite - Twinned, brownish colour in centre ; colourless in rounded ends, euhedral, inclusion free ; X82 ; Sample 5072.

Figure 2 Apatite - Twinned, brownish colour in centre, colourless in the margin, euhedral, inclusion free ; X82 ; Sample 5064.

Figure 3 Apatite - Euhedral, brownish colour in centre, colourless in outer portion, euhedral, prismatic, inclusion present ; X82 ; Sample 5064.

Figure 4 Apatite - subrounded, prismatic, apatite, bubble and black speck inclusions ; X82 ; Sample 5071.

Figure 5 Apatite - Rounded, bubble and black speck inclusions ; X82 ; Sample 5070.

Figure 6 Garnet - Euhedral, bubble and black speck inclusions ; X82 ; Sample 5068.

Figure 7 Garnet - Rounded, inclusion free ; X82 ; Sample 5072.

Figure 8 Rutile - Elongate, prismatic, apatite(?) and black speck inclusions ; X82 ; Sample 5074.

Figure 9 Epidote - Angular, concoidal fracture, inclusion free ; X82 ; Sample 5073.

Figure 10 Chlorite - Angular, inclusion free ; X82 ; Sample 5064.

Figure 11 Sphene - Subhedral, angular, apatite(?) inclusion ; X82 ; Sample 5072.

Figure 12 Tourmaline - Prismatic, angular, bubble inclusions ; X82 ; Sample 5074.

Figure 13 Tourmaline - Well rounded, inclusion free ; X82 ; Sample 5071.

Figure 14 Tourmaline - Prismatic, euhedral, apatite(?) and black speck inclusions ; X82 ; Sample 5074.

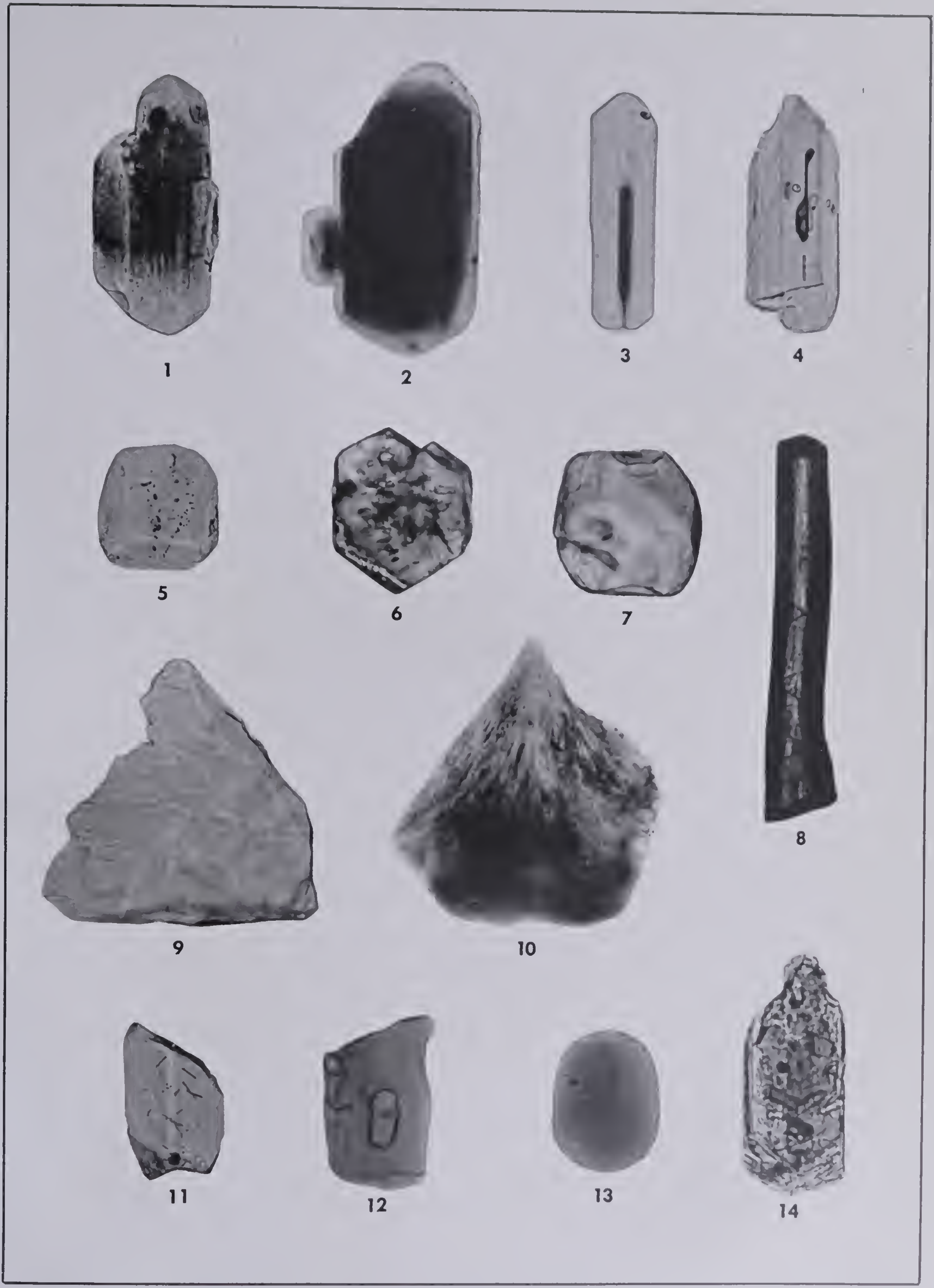

PLATE VIII.

PLATE IX

Heavy minerals from Ravenscrag sandstones

Figure 1 Zircon - Twinned, colourless, euhedral, inclusion free, prisms, pyramids and pinacoids faces ; X82 ; Sample 5432.

Figure 2 Zircon - Twinned(?), colourless, euhedral, apatite(?) inclusions, five pyramidal terminations ; X82 ; Sample 5431.

Figure 3 Zircon - Twinned, colourless, euhedral, apatite(?) inclusions , pyramidal terminations ; X82 ; Sample 5435.

Figure 4 Hyacinth - Euhedral, apatite(?) and black speck inclusions, pyramidal termination, zoned ; X82 ; Sample 5433.

Figure 5 Hyacinth - Euhedral, apatite(?) inclusions, pyramidal terminations ; X82 ; Sample 5437.

Figure 6 Zircon - Colourless, elongate, apatite (?) inclusions ; X82 ; Sample 5021.

Figure 7 Zircon - Colourless, euhedral, apatite(?) and black speck inclusions, pyramidal terminations ; X82 ; Sample 5437.

Figure 8 Hyacinth - Well rounded, inclusion free ; X82 ; Sample 5021a.

Figure 9 Zircon - Twinned(?), colourless, rounded, black speck inclusions ; X82 ; Sample 5029.

Figure 10 Zircon - Twinned(?), colourless, rounded, inclusions present ; X82 ; Sample 5029.

Figure 11 Zircon - Colourless, elongate, corroded, bubble inclusions, pyramidal termination ; X82 ; Sample 5029.

Figure 12 Zircon - Colourless, euhedral, apatite and zircon(?) inclusions, pyramidal terminations ; X82 ; Sample 5433.

Figure 13 Zircon - Colourless, euhedral, unidentified mineral inclusions, pyramidal termination ; X82 ; Sample 5437.

Figure 14 Zircon - Twinned, colourless, rounded, black speck inclusions ; X82 ; Sample 5433.

Figure 15 Garnet - Angular, bubble and black speck inclusions ; X82 ; Sample 5021.

Figure 16 Garnet - Angular, etched, inclusions present ; X64 ; Sample 5433.

Figure 17 Sphene - Euhedral, prismatic, cavity, apatite(?) inclusions ; X82 ; Sample 5024.

Figure 18 Collophane - Rounded, inclusion free ; X82 ; Sample 5029.

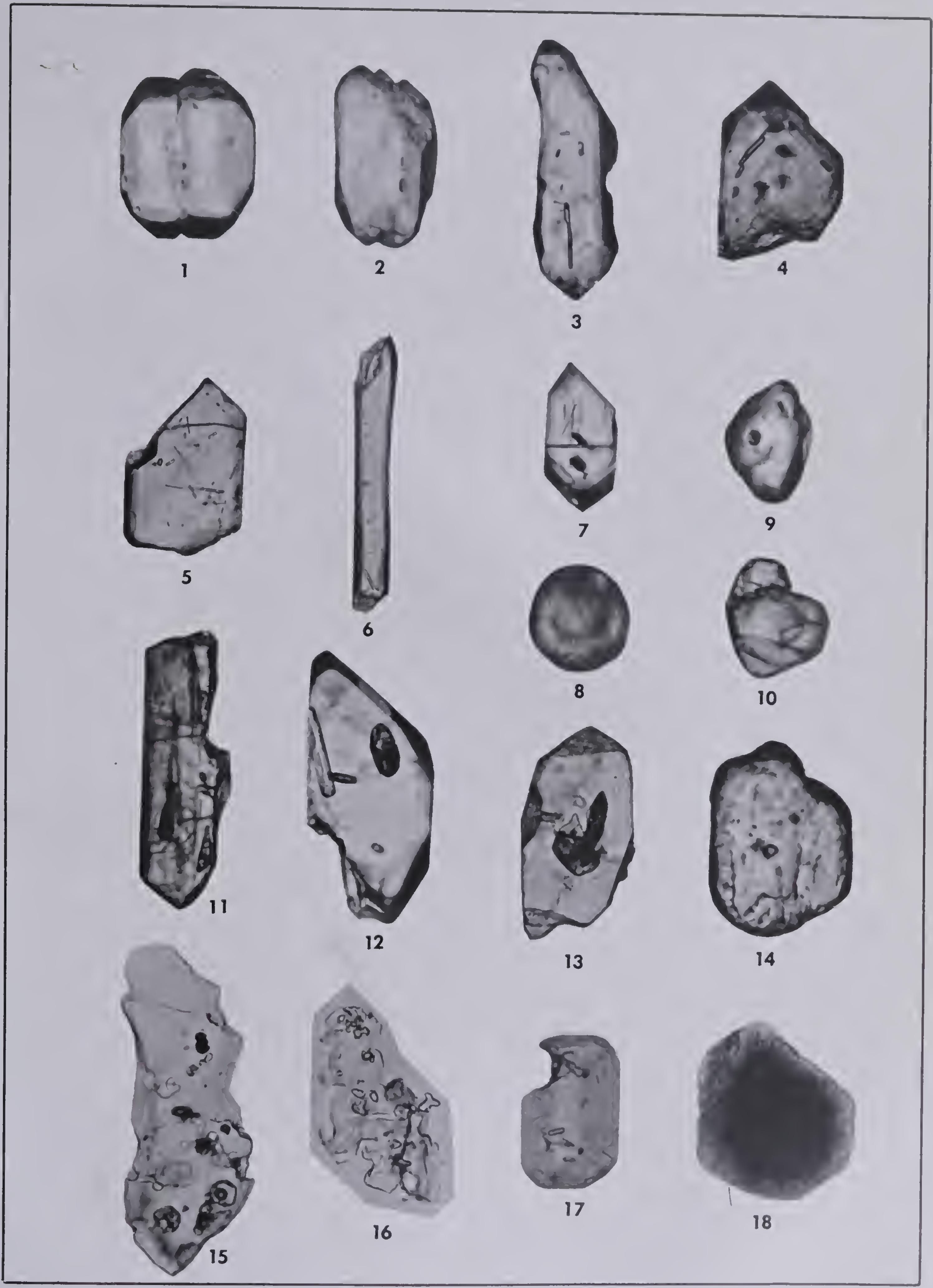

PLATE IX.

PLATE X

Heavy minerals from Ravenscrag sandstones

Figure 1	Tourmaline - Well rounded, authigenic overgrowth, bubble and dusty material inclusions ; X82 ; Sample 5433.
Figure 2	Tourmaline - Rounded, authigenic overgrowth, bubble and black speck inclusions ; X82 ; Sample 5434.
Figure 3	Tourmaline - Rounded, prismatic, authigenic overgrowth, inclusion present ; X82 ; Sample 5436.
Figure 4	Tourmaline - Rounded, authigenic overgrowth, inclusion free ; X82 ; Sample 5430.
Figure 5	Tourmaline - Rounded, authigenic overgrowth, inclusion free ; X82 ; Sample 5435.
Figure 6	Tourmaline - Well rounded, inclusion free ; X82 ; Sample 5021A.
Figure 7	Rutile - Elbow twin, prismatic, inclusion free ; X64 ; Sample 5433.
Figure 8	Rutile - Euhedral, prismatic, inclusion free ; X82 ; Sample5437.
Figure 9	Tremolite - Angular, prismatic, etched, inclusion free ; X82 ; Sample 5430.
Figure 10	Apatite - Subrounded, parallel orientation of zircon inclusions ; X82 ; Sample 5438.
Figure 11	Apatite - Subrounded, prismatic, inclusion free ; X82 ; Sample 5029.
Figure 12	Rutile - Subrounded, inclusion free ; X82 ; Sample 5437.
Figure 13	Garnet - Angular, inclusion free ; X82 ; Sample 5021a.
Figure 14	Brookite - Subrounded, striations, inclusion free ; X82 ; Sample 5021.
Figure 15	Brookite - Angular, striations, inclusion free ; X82 ; Sample 5021.
Figure 16	Brookite - Angular, prismatic, inclusion free ; X82 ; Sample 5024.
Figure 17	Epidote - Angular, inclusion free ; X82 ; Sample 5021.
Figure 18	Epidote - Angular, etched, inclusion free ; X82 ; Sample 5024.

PLATE X.